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### [Volume II, Appx00310 – Appx00620]

Nos. 22-1972, -1973, -1975, -1976

### IN THE United States Court of Appeals FOR THE FEDERAL CIRCUIT

MASIMO CORPORATION,

Appellant,

v.

APPLE INC.,

Appellee.

APPEAL FROM THE PATENT TRIAL AND APPEAL BOARD CASE NOS. IPR2020-01713, IPR2020-01716, IPR2020-01733, IPR2020-01737

### JOINT APPENDIX

Joseph R. Re, Principal Counsel Stephen C. Jensen Jarom D. Kesler Stephen W. Larson KNOBBE, MARTENS, OLSON & BEAR, LLP 2040 Main Street, 14<sup>th</sup> Floor Irvine, CA 92614 (949) 760-0404

Jeremiah S. Helm KNOBBE, MARTENS, OLSON & BEAR, LLP 1717 Pennsylvania Ave., N.W. Washington, D.C. 20006 (202) 640-6400

Masimo Corporation

Attorneys for Appellant

Lauren A. Degnan, Principal Counsel Christopher Dryer W. Karl Renner FISH & RICHARDSON P.C. 1000 Maine Ave., Suite 1000 Washington, DC 20024 Tel: (202) 783-5070

Ashley Bolt FISH & RICHARDSON P.C. 1180 Peachtree Street NE 21st Floor Atlanta, GA 30309 Tel: (404) 892-5005

Attorneys for Appellee Apple Inc.

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		W. Kenny [IPR2020-01737]	Appx23528-23562
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US010624564B1

### (12) United States Patent

Poeze et al.

### (10) Patent No.: US 10,624,564 B1

(45) **Date of Patent:** \*Apr. 21, 2020

### (54) MULTI-STREAM DATA COLLECTION SYSTEM FOR NONINVASIVE MEASUREMENT OF BLOOD CONSTITUENTS

(71) Applicant: Masimo Corporation, Irvine, CA (US)

(72) Inventors: Jeroen Poeze, Rancho Santa Margarita,
CA (US); Marcelo Lamego, Cupertino,
CA (US); Sean Merritt, Lake Forest,
CA (US); Cristiano Dalvi, Lake Forest,
CA (US); Hung Vo, Fountain Valley,
CA (US); Johannes Bruinsma,
Opeinde (NL); Ferdyan Lesmana,
Irvine, CA (US); Massi Joe E. Kiani,
Laguna Niguel, CA (US); Greg Olsen,

Lake Forest, CA (US)

(73) Assignee: Masimo Corporation, Irvine, CA (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35

U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: 16/725,292

(22) Filed: Dec. 23, 2019

### Related U.S. Application Data

- (63) Continuation of application No. 16/534,949, filed on Aug. 7, 2019, which is a continuation of application (Continued)
- (51) **Int. Cl.**A61B 5/1455 (2006.01)

  A61B 5/00 (2006.01)

  A61B 5/145 (2006.01)
- (52) **U.S. CI.**CPC ....... *A61B 5/1455* (2013.01); *A61B 5/14532* (2013.01); *A61B 5/14546* (2013.01); (Continued)

#### (58) Field of Classification Search

CPC ...... A61B 5/1455; A61B 5/14551; A61B 5/14552; A61B 5/14532; A61B 5/14546; (Continued)

### (56) References Cited

### U.S. PATENT DOCUMENTS

3,910,701 A 10/1975 Henderson et al. 4,114,604 A 9/1978 Shaw et al. (Continued)

### FOREIGN PATENT DOCUMENTS

CN 1270793 A 10/2000 CN 101484065 B 11/2011 (Continued)

### OTHER PUBLICATIONS

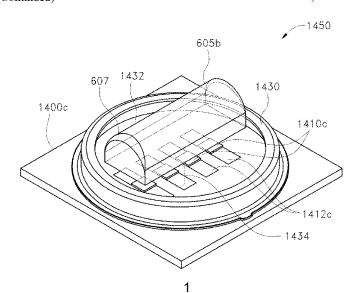
US 8,845,543 B2, 09/2014, Diab et al. (withdrawn) (Continued)

Primary Examiner — Eric F Winakur Assistant Examiner — Chu Chuan Liu (74) Attorney, Agent, or Firm — Knobbe Martens Olson & Bear LLP

### (57) ABSTRACT

The present disclosure relates to noninvasive methods, devices, and systems for measuring various blood constituents or analytes, such as glucose. In an embodiment, a light source comprises LEDs and super-luminescent LEDs. The light source emits light at at least wavelengths of about 1610 nm, about 1640 nm, and about 1665 nm. In an embodiment, the detector comprises a plurality of photodetectors arranged in a special geometry comprising one of a substantially linear substantially equal spaced geometry, a substantially linear substantially non-equal spaced geometry, and a substantially grid geometry.

### 30 Claims, 65 Drawing Sheets



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### Related U.S. Application Data

No. 16/409,515, filed on May 10, 2019, now Pat. No. 10,376,191, which is a continuation of application No. 16/261,326, filed on Jan. 29, 2019, now Pat. No. 10,292,628, which is a continuation of application No. 16/212,537, filed on Dec. 6, 2018, now Pat. No. 10,258,266, which is a continuation of application No. 14/981,290, filed on Dec. 28, 2015, now Pat. No. 10,335,068, which is a continuation of application No. 12/829,352, filed on Jul. 1, 2010, now Pat. No. 9,277,880, which is a continuation of application No. 12/534,827, filed on Aug. 3, 2009, now abandoned, said application No. 12/829,352 is a continuation-inpart of application No. 12/497,528, filed on Jul. 2, 2009, now Pat. No. 8,577,431, which is a continuation-in-part of application No. 29/323,408, filed on Aug. 25, 2008, now Pat. No. Des. 606,659, and a continuation-in-part of application No. 29/323,409, filed on Aug. 25, 2008, now Pat. No. Des. 621,516, said application No. 12/829,352 is a continuation-inpart of application No. 12/497,523, filed on Jul. 2, 2009, now Pat. No. 8,437,825, and a continuationin-part of application No. 29/323,408, filed on Aug. 25, 2009, now Pat. No. Des. 606,659, and a continuation-in-part of application No. 29/323,409, filed on Aug. 25, 2008, now Pat. No. Des. 621,516.

(60) Provisional application No. 61/086,060, filed on Aug. 4, 2008, provisional application No. 61/086,108, filed on Aug. 4, 2008, provisional application No. 61/086,063, filed on Aug. 4, 2008, provisional application No. 61/086,057, filed on Aug. 4, 2008, provisional application No. 61/091,732, filed on Aug. 25, 2008, provisional application No. 61/078,228, filed on Jul. 3, 2008, provisional application No. 61/078,207, filed on Jul. 3, 2008.

### (52) U.S. Cl.

CPC ....... A61B 5/14552 (2013.01); A61B 5/6816 (2013.01); A61B 5/6826 (2013.01); A61B 5/6829 (2013.01); A61B 5/6838 (2013.01); A61B 5/6843 (2013.01); A61B 2562/0233 (2013.01); A61B 2562/04 (2013.01); A61B 2562/046 (2013.01); A61B 2562/146 (2013.01)

### (58) Field of Classification Search

CPC ... A61B 5/6826; A61B 5/6816; A61B 5/6829; A61B 5/6838; A61B 2562/00; A61B 2562/04; A61B 2562/046; A61B 2562/06; A61B 2562/063; A61B 2562/066

See application file for complete search history.

### (56) References Cited

### U.S. PATENT DOCUMENTS

4,258,719	$\mathbf{A}$	3/1981	Lewyn
4,267,844	A	5/1981	Yamanishi
4,438,338	A	3/1984	Stitt
4,444,471	A	4/1984	Ford et al.
4,653,498	A	3/1987	New, Jr. et al.
4,655,225	A	4/1987	Dahne et al.
4,684,245	A	8/1987	Goldring
4,709,413	A	11/1987	Forrest
4,755,676	A	7/1988	Gaalema et al.
4,781,195	A	11/1988	Martin
4,805,623	A	2/1989	Jöbsis
4,825,872	A	5/1989	Tan et al.
4,880,304	A	11/1989	Jaeb et al.

4,960,128 A	10/1990	Gordon et al.
4,964,408 A	10/1990	Hink et al.
5,028,787 A	7/1991	Rosenthal et al.
	7/1991	Muz
5,041,187 A	8/1991	Hink et al.
5,043,820 A	8/1991	Wyles et al.
5,069,213 A	12/1991	Polczynski
5,069,214 A	12/1991	Samaras et al.
5,077,476 A	12/1991	Rosenthal
5,086,229 A	2/1992	Rosenthal et al.
5,099,842 A	3/1992	Mannheimer et al.
D326,715 S	6/1992	Schmidt
5,122,925 A	6/1992	Inpyn
5,131,391 A	7/1992	Sakai et al.
5,137,023 A	8/1992	Mendelson et al.
5,159,929 A	11/1992	McMillen et al.
5,163,438 A	11/1992	Gordon et al.
5,222,295 A	6/1993	Dorris, Jr.
5,222,495 A	6/1993	Clarke et al.
5,222,496 A	6/1993	Clarke et al.
5,228,449 A	7/1993	Christ et al.
5,249,576 A	10/1993	Goldberger et al.
5,250,342 A	10/1993	Lang
5,278,627 A	1/1994	Aoyagi et al.
5,297,548 A	3/1994	Pologe
5,319,355 A	6/1994	Russek
	8/1994	Mills et al.
5,337,744 A	8/1994	Branigan
5,337,745 A	8/1994	Benaron
5,341,805 A	8/1994	Stavridi et al.
5,358,519 A	10/1994	Grandjean
5,362,966 A	11/1994	Rosenthal et al.
D353,195 S	12/1994	Savage et al.
D353,196 S	12/1994	Savage et al.
5,377,676 A	1/1995	Vari et al.
D356,870 S	3/1995	Ivers et al.
D359,546 S	6/1995	Savage et al.
5,427,093 A	6/1995	Ogawa et al.
5,431,170 A	7/1995	Mathews
	8/1995	
		Savage et al.
5,437,275 A	8/1995	Amundsen et al.
5,441,054 A	8/1995	Tsuchiya
D362,063 S	9/1995	Savage et al.
5,452,717 A	9/1995	Branigan et al.
D363,120 S	10/1995	Savage et al.
5,456,252 A	10/1995	Vari et al.
5,462,051 A	10/1995	Oka et al.
5,479,934 A	1/1996	Imran
5,482,034 A	1/1996	Lewis et al.
5,482,036 A	1/1996	Diab et al.
5,490,505 A	2/1996	Diab et al.
5,490,506 A	2/1996	Takatani et al.
5,490,523 A	2/1996	Isaacson et al.
	2/1996	O'Sullivan et al.
5,497,771 A	3/1996	Rosenheimer
5,511,546 A	4/1996	Hon
5,533,511 A	7/1996	Kaspari et al.
5,534,851 A	7/1996	Russek
5,551,422 A	9/1996	Simonsen et al.
5,553,615 A	9/1996	Carim et al.
5,553,616 A	9/1996	Ham et al.
5,561,275 A	10/1996	Savage et al.
5,562,002 A	10/1996	Lalin
5,564,429 A	10/1996	Bornn et al.
5,584,296 A	12/1996	Cui et al.
5,590,649 A	1/1997	Caro et al.
5,601,079 A	2/1997	Wong et al.
5,602,924 A	2/1997	Durand et al.
D378,414 S	3/1997	Allen et al.
5,623,925 A	4/1997	Swenson et al.
5,625,458 A	4/1997	Alfano et al.
5,632,272 A	5/1997	Diab et al.
5,638,816 A	6/1997	Kiani-Azarbayjany et al
5,638,818 A	6/1997	Diab et al.
5,645,440 A	7/1997	Tobler et al.
5,676,143 A	10/1997	Simonsen et al.
5,685,299 A	11/1997	Diab et al.
5,687,717 A	11/1997	Halpern et al.
D390,666 S	2/1998	Lagerlof

Case: 22-1972 Document: 33-2 Page: 10 Filed: 05/11/2023

(56)		Referen	ces Cited	6,278,522			Lepper, Jr. et al.
	U.S. I	PATENT	DOCUMENTS	6,278,889 6,280,213		8/2001	Robinson Tobler et al.
	0.0.1			6,285,896	B1	9/2001	Tobler et al.
	9,203 A		Oka et al.	6,297,969 6,301,493			Mottahed Marro et al.
	3,830 S 3,262 A		Tobler et al. Lepper, Jr. et al.	6,308,089	В1		von der Ruhr et al.
5,750	),927 A	5/1998	Baltazar	6,317,627			Ennen et al.
	2,914 A 3,644 A		Delonzor et al. Diab et al.	6,321,100 D452,012		11/2001 12/2001	
	),910 A		Lepper, Jr. et al.	6,325,761	B1	12/2001	Jay
,	5,131 A		Kondo et al.	6,334,065 6,343,223			Al-Ali et al. Chin et al.
	9,785 A 2,757 A		Diab et al. Diab et al.	6,343,224		1/2002	
5,785	5,659 A	7/1998	Caro et al.	6,345,194			Nelson et al.
	1,347 A 2,052 A		Flaherty et al. Isaacson et al.	6,349,228 6,353,750			Kiani et al. Kimura et al.
	5,300 A	8/1998		6,356,203	В1	3/2002	Halleck et al.
	),349 A		Isaacson et al.	6,360,113 6,360,114			Dettling Diab et al.
	7,247 A ),734 A		Merchant et al. Caro et al.	6,360,115			Greenwald et al.
5,823	3,950 A	10/1998	Diab et al.	D455,834			Donars et al.
	5,885 A ),131 A		Helgeland Caro et al.	6,368,283 6,371,921			Xu et al. Caro et al.
	),131 A	11/1998		6,377,829	В1	4/2002	
	3,618 A		Caro et al.	6,388,240 6,397,091			Schulz et al. Diab et al.
	3,070 S 1,178 A	12/1998	Maeda et al. Aronow	6,430,437		8/2002	
5,860	,919 A	1/1999	Kiani-Azarbayjany et al.	6,430,525			Weber et al.
	),929 A 2,235 A		Mills et al. Lewis et al.	D463,561 6,463,187			Fukatsu et al. Baruch et al.
	3,357 A	5/1999		6,463,311	B1	10/2002	Diab
	1,654 A		Wohltmann et al.	6,470,199 6,470,893		10/2002 10/2002	Kopotic et al.
	9,134 A 1,925 A	7/1999 8/1999	Tobler et al.	6,475,153			Khair et al.
5,940	),182 A	8/1999	Lepper, Jr. et al.	RE37,922		12/2002	
	7,840 A 1,870 S		Terasawa et al. Saltzstein et al.	6,491,647 6,501,975			Bridger et al. Diab et al.
	7,343 A	11/1999		6,505,059	В1	1/2003	Kollias et al.
	5,855 A		Kiani et al.	6,515,273 6,516,289		2/2003	Al-Ali David et al.
	7,343 A 2,952 A		Mills et al. Diab et al.	6,519,487		2/2003	
6,011	,986 A	1/2000	Diab et al.	6,522,521			Mizuno et al.
	3,673 A 7,452 A		Chin et al. Flaherty et al.	6,525,386 6,526,300			Mills et al. Kiani et al.
	5,642 A		Diab et al.	6,541,756	B2	4/2003	Schulz et al.
	5,509 A		Caro et al.	6,542,764 6,556,852		4/2003 4/2003	Al-Ali et al. Schulze et al.
	9,727 A 7,462 A		Crothall Diab et al.	6,580,086		6/2003	
6,081	,735 A	6/2000	Diab et al.	6,584,336			Ali et al.
	8,607 A 2,856 A		Diab et al. Clarence et al.	6,595,316 6,597,932		7/2003 7/2003	Cybulski et al. Tian et al.
	),522 A		Lepper, Jr. et al.	6,597,933			Kiani et al.
	1,597 A		Shehada	6,606,509 6,606,511			Schmitt Ali et al.
	3,521 A 9,675 A	10/2000	Marro et al. Jav	D481,459	S	10/2003	Nahm
6,144	1,866 A	11/2000	Miesel et al.	6,632,181 6,636,759			Flaherty et al. Robinson
	1,868 A 1,516 A	11/2000	Parker Kiani-Azarbayjany et al.	6,639,668			Trepagnier
6,152	2,754 A	11/2000	Gerhardt et al.	6,639,867		10/2003	
	7,850 A		Diab et al. Mills et al.	6,640,116 6,643,530		10/2003	Diab et al.
	5,005 A 7,258 A		Schmidt et al.	6,650,917	B2	11/2003	Diab et al.
6,172	2,743 B1		Kley et al.	6,650,939 6,654,624			Takpke, II et al. Diab et al.
	5,752 B1 1,958 B1		Say et al. Steuer et al.	6,658,276			Kiani et al.
6,184	1,521 B1	2/2001	Coffin, IV et al.	6,661,161			Lanzo et al.
	2,930 B1 5,830 B1	3/2001	Plesko Diab et al.	6,668,185 6,671,526			Toida Aoyagi et al.
	3,063 B1		Chaiken et al.	6,671,531			Al-Ali et al.
6,229	,856 B1	5/2001	Diab et al.	6,678,543			Diab et al.
	2,609 B1 5,872 B1		Snyder et al. Diab et al.	6,681,133 6,684,090			Chaiken et al. Ali et al.
6,241	,680 B1	6/2001		6,684,091	B2	1/2004	Parker
	,683 B1		Macklem et al.	6,697,656		2/2004	
	1,684 B1 3,097 B1		Amano et al. Aronow et al.	6,697,657 6,697,658		2/2004 2/2004	Shehada et al.
	5,523 B1		Diab et al.	RE38,476	E		Diab et al.
6,263	3,222 B1	7/2001	Diab et al.	6,699,194	В1	3/2004	Diab et al.

Case: 22-1972 Document: 33-2 Page: 11 Filed: 05/11/2023

(56)		Referen	ces Cited	7,215,986 B2 7,221,971 B2	5/2007 5/2007	
	U.S.	PATENT	DOCUMENTS	7,225,006 B2		Al-Ali et al.
				7,225,007 B2 RE39,672 E	5/2007	Al-Ali Shehada et al.
	,804 B2 ,492 E		Al-Ali et al. Diab et al.	7,227,156 B2		Colvin, Jr. et al.
6,721	,582 B2		Trepagnier et al.	7,230,227 B2		Wilcken et al.
	,585 B1	4/2004		D547,454 S 7,239,905 B2	7/2007 7/2007	Hsieh Kiani-Azarbayjany et al.
	,075 B2 ,560 B2	4/2004 4/2004	Kollias et al.	7,245,953 B1	7/2007	Parker
6,735	,459 B2	5/2004	Parker	D549,830 S 7,254,429 B2		Behar et al. Schurman et al.
	,060 B2 ,254 B2		Diab et al. O'Neil et al.	7,254,431 B2	8/2007	
	,607 B2	7/2004		7,254,433 B2		Diab et al.
	,028 B1 ,994 B2		Ali et al. Kiani et al.	7,254,434 B2 D550,364 S		Schulz et al. Glover et al.
	,568 B2		Chance	D551,350 S	9/2007	Lorimer et al.
6,792	,300 B1		Diab et al.	7,272,425 B2 7,274,955 B2	9/2007	Al-Ali Kiani et al.
	,799 B2 ,535 B2		Mendelson Palti et al.	D553,248 S	10/2007	
6,813	,511 B2	11/2004	Diab et al.	D554,263 S	10/2007	
	,010 B2 ,241 B2		Seetharaman et al. Grubisic et al.	7,280,858 B2 7,289,835 B2		Al-Ali et al. Mansfield et al.
	,741 B2	11/2004		7,292,883 B2	11/2007	De Felice et al.
6,822	,564 B2	11/2004		7,295,866 B2 D562,985 S	11/2007	Al-Ali Brefka et al.
	,419 B2 ,711 B2		Diab et al. Mills et al.	7,328,053 B1		Diab et al.
6,831	,266 B2	12/2004	Paritsky et al.	7,332,784 B2		Mills et al.
	,787 B2 ,788 B2	2/2005 2/2005	Weber et al.	7,340,287 B2 7,341,559 B2		Mason et al. Schulz et al.
	,083 B2		Caro et al.	7,343,186 B2	3/2008	Lamego et al.
D502	,655 S	3/2005		D566,282 S D567,125 S		Al-Ali et al. Okabe et al.
	,639 B2 ,788 B2	3/2005 5/2005	Al-Alı Khair et al.	7,355,512 B1	4/2008	
6,898	,452 B2	5/2005	Al-Ali et al.	7,356,365 B2		Schurman
	,413 B2 ,345 B2		Rantala et al. Al-Ali et al.	7,365,923 B2 D569,001 S		Hargis et al. Omaki
	,862 S		Behar et al.	D569,521 S	5/2008	Omaki
	,268 B1		Kiani-Azarbayjany et al.	7,371,981 B2 7,373,193 B2		Abdul-Hafiz Al-Ali et al.
	,570 B2 ,305 B2		Kiani et al. Flaherty et al.	7,373,193 B2 7,373,194 B2		Weber et al.
6,943	,348 B1	9/2005	Coffin, IV	7,376,453 B1		Diab et al.
	,687 B2 ,625 S	9/2005	Al-Ali Widener et al.	7,377,794 B2 7,377,899 B2		Al Ali et al. Weber et al.
6,961	,598 B2	11/2005		7,383,070 B2	6/2008	Diab et al.
	,792 B1	11/2005		7,395,189 B2 7,415,297 B2		Qing et al. Al-Ali et al.
	,812 B2 ,764 B2	12/2005 1/2006	Mason et al.	7,428,432 B2	9/2008	Ali et al.
6,993	,371 B2		Kiani et al.	7,438,683 B2 7,440,787 B2	10/2008 10/2008	Al-Ali et al.
	,461 S ,400 B2	2/2006	Harju Mizuyoshi	7,454,240 B2		Diab et al.
	,427 B2		Ali et al.	7,467,002 B2		Weber et al.
	,904 B2		Weber et al.	7,469,157 B2 7,471,969 B2		Diab et al. Diab et al.
	,338 B2 ,339 B2		Weber et al. Diab et al.	7,471,971 B2	12/2008	Diab et al.
7,015	,451 B2		Dalke et al.	7,483,729 B2 7,483,730 B2	1/2009	Al-Ali et al. Diab et al.
	,233 B2 ,619 B2		Ali et al. Cranford	7,489,958 B2		Diab et al.
7,027	,849 B2	4/2006	Al-Ali	7,496,391 B2 7,496,393 B2		Diab et al.
	,749 B2 ,449 B2	4/2006 5/2006		D587,657 S		Diab et al. Al-Ali et al.
	,060 B2		Flaherty et al.	7,499,741 B2		Diab et al.
	,918 B2	5/2006		7,499,835 B2 7,500,950 B2	3/2009 3/2009	Weber et al. Al-Ali et al.
	,054 B2 ,687 B1	5/2006 5/2006	Reuss et al.	7,509,153 B2	3/2009	Blank et al.
7,060	,963 B2	6/2006	Maegawa et al.	7,509,154 B2 7,509,494 B2	3/2009 3/2009	Diab et al. Al-Ali
	,893 B2 ,757 B2		Mills et al. Larson et al.	7,510,849 B2		Schurman et al.
	,052 B2	8/2006	Mason et al.	7,519,327 B2	4/2009	
	,054 B2		Abdul-Hafiz et al.	7,526,328 B2 7,530,942 B1	4/2009 5/2009	Diab et al.
	,815 B2 ,641 B2		O'Neil et al. Schulz et al.	7,530,942 B1 7,530,949 B2	5/2009	Al Ali et al.
7,142	,901 B2	11/2006	Kiani et al.	7,530,955 B2	5/2009	Diab et al.
	,561 B2 ,031 S	1/2006	Diab Barrett et al.	7,563,110 B2 7,596,398 B2	7/2009	Al-Ali et al. Al-Ali et al.
	,031 S ,164 S		Shigemori et al.	7,596,398 B2 7,601,123 B2		Tweed et al.
7,186	,966 B2	3/2007	Al-Ali	7,606,606 B2	10/2009	Laakkonen
	,261 B2	3/2007		D603,966 S		Jones et al.
7,215	,984 B2	5/2007	DIAD	7,618,375 B2	11/2009	Flaherty

Case: 22-1972 Document: 33-2 Page: 12 Filed: 05/11/2023

(56)		Referen	ces Cited	8,145,287			Diab et al.
	ЦS	PATENT	DOCUMENTS	8,150,487 1 8,175,672		4/2012 5/2012	Diab et al. Parker
	0.5.	121112111	DOCUMENTS	8,180,420	B2		Diab et al.
D606,6:			Kiani et al.	8,182,443 1 8,185,180 1		5/2012	Kıanı Diab et al.
7,647,03 D609,19			Al-Ali et al. Al-Ali et al.	8,190,223	B2		Al-Ali et al.
7,657,29	94 B2		Eghbal et al.	8,190,227	B2		Diab et al.
7,657,29	95 B2	2/2010	Coakley et al.	8,203,438			Kiani et al.
7,657,29			Raridan et al. Al-Ali et al.	8,203,704 8,204,566			Merritt et al. Schurman et al.
D614,30 RE41,3		5/2010		8,219,170	B2	7/2012	Hausmann et al.
7,726,20		6/2010	Ruotoistenmäki	8,219,172			Schurman et al.
7,729,73			Al-Ali et al.	8,224,411 1 8,228,181 1		7/2012	Al-Ali et al.
7,734,32 7,740,53		6/2010 6/2010		8,229,532		7/2012	
7,740,5			Maschke et al.	8,229,533	B2		Diab et al.
7,761,11			Al-Ali et al.	8,233,955 8,244,325			Al-Ali et al. Al-Ali et al.
7,761,12 7,764,93			Al-Ali et al. Dalke et al.	8,244,326			Ninomiya et al.
D621,5			Kiani et al.	8,255,026		8/2012	Al-Ali
7,791,1		9/2010		8,255,027 8,255,028			Al-Ali et al. Al-Ali et al.
7,801,53 7,809,4		9/2010 10/2010		8,260,577			Weber et al.
7,822,4			Schurman et al.	8,265,723	B1		McHale et al.
RE41,9	12 E	11/2010		8,274,360		9/2012 10/2012	Sampath et al.
7,844,3		11/2010 11/2010	Kiani et al.	8,280,473 1 8,289,130 1			Nakajima et al.
7,844,3 7,844,3		11/2010		8,301,217	B2		Al-Ali et al.
7,862,52	23 B2	1/2011	Ruotoistenmaki	8,306,596			Schurman et al.
7,865,22			Weber et al.	8,310,336 1 8,315,683 1	B2 B2		Muhsin et al. Al-Ali et al.
7,869,84 7,873,49			Ollerdessen et al. Weber et al.	RE43,860		12/2012	
7,880,60	06 B2	2/2011	Al-Ali	8,280,469			Baker, Jr.
7,880,62			Al-Ali et al.	8,332,006 1 8,337,403 1			Naganuma et al. Al-Ali et al.
7,884,3 7,891,3			Hamada Al-Ali et al.	8,346,330			Lamego
7,894,80	58 B2		Al-Ali et al.	8,353,842	B2	1/2013	Al-Ali et al.
7,899,50			Xu et al.	8,355,766 1 8,359,080 1			MacNeish, III et al. Diab et al.
7,899,50 7,899,5			Al-Ali et al. Hoarau	8,364,223			Al-Ali et al.
7,899,5			Trepagnier et al.	8,364,226	B2	1/2013	Diab et al.
7,904,13	32 B2	3/2011	Weber et al.	8,364,389			Dorogusker et al. Lamego
7,909,7° 7,910,8°		3/2011 3/2011	Popov et al.	8,374,665 8,380,272			Barrett et al.
7,910,8			Al-Ali et al.	8,385,995	B2	2/2013	Al-ali et al.
7,937,12	28 B2	5/2011	Al-Ali	8,385,996 8,388,353			Smith et al.
7,937,13			Mason et al. Diab et al.	8,399,822		3/2013	Kiani et al. Al-Ali
7,937,13 7,941,19		5/2011		8,401,602		3/2013	
7,951,0	86 B2	5/2011	Flaherty et al.	8,405,608			Al-Ali et al.
7,957,73			Lamego et al.	8,414,499 1 8,418,524 1		4/2013	Al-Ali et al. Al-Ali
7,962,13 7,962,19	oo b∠ 90 B1	6/2011	Kiani et al. Diab et al.	8,421,022			Rozenfeld
7,976,4	72 B2	7/2011	Kiani	8,423,106			Lamego et al.
7,988,63		8/2011		8,428,674 8,428,967			Duffy et al. Olsen et al.
7,990,33 7,991,4		8/2011 8/2011	Ali et al.	8,430,817			Al-Ali et al.
8,000,70	51 B2	8/2011	Al-Ali	8,437,825			Dalvi et al.
8,008,03			Bellott et al.	8,452,364 1 8,455,290 1			Hannula et al. Siskavich
RE42,7: 8,019,40			Kiani-Azarbayjany et al. Diab et al.	8,457,703	B2	6/2013	
8,028,70	01 B2	10/2011	Al-Ali et al.	8,457,707		6/2013	
8,029,70			Bellott et al.	8,463,349 8,466,286			Diab et al. Bellot et al.
8,036,72 8,036,72			Schurman et al. Diab et al.	8,471,713			Poeze et al.
8,044,99	98 B2	10/2011		8,473,020			Kiani et al.
8,046,04			Ali et al.	8,483,787 8,489,364			Al-Ali et al. Weber et al.
8,046,04 8,046,04			Diab et al. Diab et al.	8,498,684			Weber et al.
8,048,04		11/2011		8,504,128	B2	8/2013	Blank et al.
8,050,7			Al-Ali et al.	8,509,867			Workman et al.
8,071,93 RE43,10		12/2011 2/2012	Besko et al.	8,515,509 8,523,781		8/2013 9/2013	Bruinsma et al.
8,118,62			Al-Ali et al.	8,529,301			Al-Ali et al.
8,126,5	28 B2	2/2012	Diab et al.	8,532,727	B2	9/2013	Ali et al.
8,126,53			Crowley	8,532,728			Diab et al.
8,128,5° 8,130,10			Diab et al. Al-Ali et al.	D692,145 (8,547,209 )			Al-Ali et al. Kiani et al.
8,130,10	JJ <b>D</b> Z	3/2012	AI-AII CI aI.	0,547,209	DΔ	10/2013	KIAIII CI AI.

Case: 22-1972 Document: 33-2 Page: 13 Filed: 05/11/2023

(56)		Referen	ces Cited		8,868,147 B2		Stippick et al.
	U.S.	PATENT	DOCUMENTS		8,868,150 B2 8,870,792 B2	10/2014	Al-Ali et al. Al-Ali et al.
					8,886,271 B2		Kiani et al.
	8,548,548 B2	10/2013			8,888,539 B2		Al-Ali et al. Diab et al.
	8,548,549 B2		Schurman et al. Al-Ali et al.		8,888,708 B2 8,892,180 B2		Weber et al.
	8,548,550 B2 8,560,032 B2		Al-Ali et al.		8,897,847 B2	11/2014	Al-Ali
	8,560,034 B1		Diab et al.		8,909,310 B2		Lamego et al.
	8,570,167 B2	10/2013			8,911,377 B2 8,912,909 B2	12/2014	Al-Ali et al.
	8,570,503 B2 8,571,617 B2	10/2013	Vo et al. Reichgott et al.		8,912,909 B2 8,920,317 B2		Al-Ali et al.
	8,571,617 B2 8,571,618 B1		Lamego et al.		8,921,699 B2		Al-Ali et al.
	8,571,619 B2	10/2013	Al-Ali et al.		8,922,382 B2		Al-Alı et al.
	8,577,431 B2		Lamego et al.		8,929,964 B2 8,942,777 B2		Al-Ali et al. Diab et al.
	8,581,732 B2 8,584,345 B2		Al-Ali et al. Al-Ali et al.		8,948,834 B2		Diab et al.
	8,588,880 B2		Abdul-Hafiz et al.		8,948,835 B2	2/2015	
	8,600,467 B2		Al-Ali et al.		8,965,471 B2		Lamego
	8,602,971 B2	12/2013			8,983,564 B2 8,989,831 B2	3/2015 3/2015	Al-Ali et al.
	8,606,342 B2 8,615,290 B2	12/2013	Lin et al.		8,996,085 B2		Kiani et al.
	8,626,255 B2		Al-Ali et al.		8,998,809 B2	4/2015	
	8,630,691 B2		Lamego et al.		9,028,429 B2 9,037,207 B2		Telfort et al. Al-Ali et al.
	8,634,889 B2 8,641,631 B2		Al-Ali et al. Sierra et al.		9,060,721 B2		Reichgott et al.
	8,652,060 B2	2/2014			9,066,666 B2	6/2015	Kiani
	8,655,004 B2		Prest et al.		9,066,680 B1		Al-Ali et al.
	8,663,107 B2	3/2014			9,072,437 B2 9,072,474 B2		Paalasmaa Al-Ali et al.
	8,666,468 B1 8,667,967 B2	3/2014	Al-Ali et al.		9,078,560 B2		Schurman et al.
	8,670,811 B2		O'Reilly		9,081,889 B2		Ingrassia, Jr. et al.
	8,670,814 B2		Diab et al.		9,084,569 B2 9,095,316 B2		Weber et al. Welch et al.
	8,676,286 B2 8,682,407 B2	3/2014 3/2014	Weber et al.		9,106,038 B2		Telfort et al.
	RE44,823 E	4/2014			9,107,625 B2	8/2015	Telfort et al.
	RE44,875 E		Kiani et al.		9,107,626 B2		Al-Ali et al.
	8,688,183 B2		Bruinsma et al.		9,113,831 B2 9,113,832 B2	8/2015 8/2015	
	8,690,799 B2 8,700,111 B2		Telfort et al. LeBoeuf et al.		9,119,595 B2		Lamego
	8,700,111 B2 8,700,112 B2	4/2014			9,131,881 B2	9/2015	Diab et al.
	8,702,627 B2		Telfort et al.		9,131,882 B2	9/2015 9/2015	Al-Ali et al.
	8,706,179 B2 8,712,494 B1	4/2014	Parker MacNeish, III et al.		9,131,883 B2 9,131,917 B2		Telfort et al.
	8,715,206 B2		Telfort et al.		9,138,180 B1	9/2015	Coverston et al.
	8,718,735 B2		Lamego et al.		9,138,182 B2		Al-Ali et al.
	8,718,737 B2		Diab et al.		9,138,192 B2 9,142,117 B2		Weber et al. Muhsin et al.
	8,718,738 B2 8,720,249 B2	5/2014	Blank et al.		9,153,112 B1		Kiani et al.
	8,721,541 B2		Al-Ali et al.		9,153,121 B2		Kiani et al.
	8,721,542 B2		Al-Ali et al.		9,161,696 B2		Al-Ali et al. Al-Ali et al.
	8,723,677 B1 8,740,792 B1	5/2014	Kiani Kiani et al.		9,161,713 B2 9,167,995 B2		Lamego et al.
	8,754,776 B2		Poeze et al.		9,176,141 B2	11/2015	Al-Ali et al.
	8,755,535 B2		Telfort et al.		9,186,102 B2		Bruinsma et al.
	8,755,856 B2		Diab et al.		9,192,312 B2 9,192,329 B2	11/2015 11/2015	
	8,755,872 B1 8,760,517 B2		Marinow Sarwar et al.		9,192,351 B1		Telfort et al.
	8,761,850 B2		Lamego		9,195,385 B2		Al-Ali et al.
	8,764,671 B2	7/2014			9,210,566 B2 9,211,072 B2		Ziemianska et al.
	8,768,423 B2 8,771,204 B2		Shakespeare et al. Telfort et al.		9,211,072 B2 9,211,095 B1	12/2015 12/2015	
	8,777,634 B2		Kiani et al.		9,218,454 B2	12/2015	Kiani et al.
	8,781,543 B2	7/2014	Diab et al.		9,226,696 B2	1/2016	
	8,781,544 B2		Al-Ali et al.		9,241,662 B2 9,245,668 B1		Al-Ali et al. Vo et al.
	8,781,549 B2 8,788,003 B2		Al-Ali et al. Schurman et al.		9,259,185 B2		Abdul-Hafiz et al.
	8,790,268 B2	7/2014			9,267,572 B2		Barker et al.
	8,801,613 B2		Al-Ali et al.		9,277,880 B2 9,289,167 B2		Poeze et al. Diab et al.
	8,821,397 B2 8,821,415 B2		Al-Ali et al. Al-Ali et al.		9,295,421 B2		Kiani et al.
	8,830,449 B1		Lamego et al.		9,307,928 B1		Al-Ali et al.
	8,831,700 B2	9/2014	Schurman et al.		9,311,382 B2		Varoglu et al.
	8,838,210 B2		Wood et al.		9,323,894 B2	4/2016	
	8,840,549 B2 8,847,740 B2		Al-Ali et al. Kiani et al.		D755,392 S 9,326,712 B1	5/2016	Hwang et al.
	8,849,365 B2		Smith et al.		9,333,316 B2	5/2016	
	8,852,094 B2		Al-Ali et al.		9,339,220 B2		Lamego et al.
	8,852,994 B2	10/2014	Wojtczuk et al.		9,341,565 B2	5/2016	Lamego et al.
				_			

Case: 22-1972 Document: 33-2 Page: 14 Filed: 05/11/2023

(56)	Referen	ces Cited	9,782,077 B2		Lamego et al.
U.S.	PATENT	DOCUMENTS	9,782,110 B2 9,787,568 B2	10/2017 10/2017	Lamego et al.
0.0.	11112111	DOCOMENTO	9,788,735 B2	10/2017	Al-Ali
9,351,673 B2		Diab et al.	9,788,768 B2 9,795,300 B2	10/2017 10/2017	Al-Ali et al.
9,351,675 B2 9,357,665 B2		Al-Ali et al. Myers et al.	9,795,310 B2	10/2017	
9,364,181 B2		Kiani et al.	9,795,358 B2	10/2017	
9,368,671 B2		Wojtczuk et al.	9,795,739 B2 9,801,556 B2	10/2017 10/2017	Al-Ali et al.
9,370,325 B2 9,370,326 B2		Al-Ali et al. McHale et al.	9,801,588 B2		Weber et al.
9,370,335 B2		Al-ali et al.	9,808,188 B1	11/2017	Perea et al.
9,375,185 B2		Ali et al.	9,814,418 B2 9,820,691 B2	11/2017 11/2017	Weber et al.
9,386,953 B2 9,386,961 B2	7/2016	Al-Ali Al-Ali et al.	9,833,152 B2		Kiani et al.
9,392,945 B2		Al-Ali et al.	9,833,180 B2	12/2017	Shakespeare et al.
9,397,448 B2		Al-Ali et al.	9,838,775 B2		Qian et al. Al-Ali et al.
9,408,542 B1 9,436,645 B2		Kinast et al. Al-Ali et al.	9,839,379 B2 9,839,381 B1		Weber et al.
9,445,759 B1		Lamego et al.	9,847,002 B2	12/2017	Kiani et al.
9,466,919 B2	10/2016	Kiani et al.	9,847,749 B2		Kiani et al.
9,474,474 B2 9,480,422 B2	10/2016 11/2016	Lamego et al.	9,848,800 B1 9,848,806 B2		Lee et al. Al-Ali et al.
9,480,422 B2 9,480,435 B2	11/2016		9,848,807 B2	12/2017	Lamego
9,489,081 B2	11/2016	Anzures et al.	9,848,823 B2		Raghuram et al.
9,492,110 B2 9,497,534 B2		Al-Ali et al. Prest et al.	9,861,298 B2 9,861,304 B2		Eckerbom et al. Al-Ali et al.
9,497,334 B2 9,510,779 B2		Poeze et al.	9,861,305 B1	1/2018	Weber et al.
9,517,024 B2	12/2016	Kiani et al.	9,866,671 B1	1/2018	Thompson et al. Maani et al.
9,526,430 B2 9,532,722 B2		Srinivas et al.	9,867,575 B2 9,867,578 B2		Al-Ali et al.
9,532,722 B2 9,538,949 B2		Lamego et al. Al-Ali et al.	9,872,623 B2	1/2018	
9,538,980 B2	1/2017	Telfort et al.	9,876,320 B2		Coverston et al.
9,549,696 B2 9,553,625 B2		Lamego et al. Hatanaka et al.	9,877,650 B2 9,877,686 B2		Muhsin et al. Al-Ali et al.
9,555,025 B2 9,554,737 B2		Schurman et al.	9,891,079 B2	2/2018	
9,560,996 B2	2/2017	Kiani	9,895,107 B2		Al-Ali et al.
9,560,998 B2		Al-Ali et al.	9,898,049 B2 9,913,617 B2		Myers et al. Al-Ali et al.
9,566,019 B2 9,579,039 B2		Al-Ali et al. Jansen et al.	9,918,646 B2		Singh Alvarado et al.
9,591,975 B2	3/2017	Dalvi et al.	9,924,893 B2		Schurman et al.
9,593,969 B2	3/2017		9,924,897 B1 9,936,917 B2		Abdul-Hafiz Poeze et al.
9,622,692 B2 9,622,693 B2	4/2017	Lamego et al. Diab	9,943,269 B2		Muhsin et al.
D788,312 S	5/2017	Al-Ali et al.	9,949,676 B2 9,952,095 B1	4/2018	
9,636,055 B2 9,636,056 B2		Al-Ali et al. Al-Ali	9,955,937 B2		Hotelling et al. Telfort
9,649,054 B2		Lamego et al.	9,965,946 B2	5/2018	
9,651,405 B1		Gowreesunker et al.	9,980,667 B2 D820,865 S		Kiani et al. Muhsin et al.
9,662,052 B2 9,668,676 B2		Al-Ali et al. Culbert	9,986,919 B2		Lamego et al.
9,668,679 B2		Schurman et al.	9,986,952 B2	6/2018	Dalvi et al.
9,668,680 B2		Bruinsma et al.	9,989,560 B2 9,993,207 B2		Poeze et al. Al-Ali et al.
9,668,703 B2 9,675,286 B2	6/2017 6/2017		10,007,758 B2		Al-Ali et al.
9,687,160 B2	6/2017		D822,215 S	7/2018	Al-Ali et al.
9,693,719 B2		Al-Ali et al.	D822,216 S 10,010,276 B2		Barker et al. Al-Ali et al.
9,693,737 B2 9,697,928 B2	7/2017 7/2017	Al-Ali et al.	10,010,270 B2 10,032,002 B2		Kiani et al.
9,699,546 B2		Qian et al.	10,039,080 B2		Miller et al.
9,700,249 B2		Johnson et al.	10,039,482 B2 10,052,037 B2		Al-Ali et al. Kinast et al.
9,716,937 B2 9,717,425 B2		Qian et al. Kiani et al.	10,055,121 B2		Chaudhri et al.
9,717,458 B2		Lamego et al.	10,058,275 B2		Al-Ali et al.
9,723,997 B1		Lamego	10,064,562 B2 10,066,970 B2	9/2018	Al-Alı Gowreesunker et al.
9,724,016 B1 9,724,024 B2	8/2017	Al-Ali et al.	10,076,257 B2		Lin et al.
9,724,025 B1		Kiani et al.	10,078,052 B2		Ness et al.
9,730,640 B2		Diab et al.	10,086,138 B1 10,092,200 B2		Novak, Jr. Al-Ali et al.
9,743,887 B2 9,749,232 B2		Al-Ali et al. Sampath et al.	10,092,200 B2 10,092,249 B2		Kiani et al.
9,750,442 B2	9/2017	Olsen	10,098,550 B2	10/2018	Al-Ali et al.
9,750,443 B2		Smith et al.	10,098,591 B2		Al-Ali et al.
9,750,461 B1 9,775,545 B2		Telfort Al-Ali et al.	10,098,610 B2 D833,624 S		Al-Ali et al. DeJong et al.
9,775,546 B2		Diab et al.	10,123,726 B2		Al-Ali et al.
9,775,570 B2	10/2017	Al-Ali	10,130,289 B2	11/2018	Al-Ali et al.
9,778,079 B1		Al-Ali et al.	10,130,291 B2		Schurman et al.
9,781,984 B2	10/2017	Baranski et al.	D835,282 S	12/2018	Barker et al.

Case: 22-1972 Document: 33-2 Page: 15 Filed: 05/11/2023

(56)	]	Referen	ces Cited	10,470,695		11/2019	
	U.S. P	ATENT	DOCUMENTS	10,471,159 10,478,107			Lapotko et al. Kiani et al.
	0.0.1.			2002/0045836	A1		Alkawwas
D835,283			Barker et al.	2002/0099279 2002/0111546			Pfeiffer et al. Cook et al.
D835,284 D835,285			Barker et al. Barker et al.	2003/0036690			Geddes et al.
10,149,616			Al-Ali et al.	2003/0158501			Uchida et al.
10,154,815			Al-Ali et al.	2004/0054290 2004/0114783			Chance Spycher et al.
10,159,412 10,188,296			Lamego et al. Al-Ali et al.	2004/0114783			Teller et al.
10,188,331			Al-Ali et al.	2005/0020927		1/2005	Blondeau et al.
10,188,348			Kiani et al.	2005/0054940 2005/0116820		3/2005	Almen Goldreich
RE47,218 RE47,244		2/2019	Ali-Ali Kiani et al.	2005/0110820			Yamamoto et al.
RE47,244 RE47,249			Kiani et al.	2006/0005944		1/2006	Wang et al.
10,194,847	B2	2/2019		2006/0020180		1/2006	
10,194,848			Kiani et al.	2006/0025659 2006/0161054			Kiguchi et al. Reuss et al.
10,201,298 10,205,272			Al-Ali et al. Kiani et al.	2006/0253010			Brady et al.
10,205,291			Scruggs et al.	2006/0258928			Ortner et al.
10,213,108		2/2019		2007/0073117 2007/0106172		5/2007 5/2007	Raridan Abreu
10,219,706 10,219,746		3/2019	Al-Ali McHale et al.	2007/0149864			Laakkonen
10,226,187			Al-Ali et al.	2007/0208395			Leclerc et al.
10,226,576		3/2019		2007/0238955 2007/0249916			Tearney et al. Pesach et al.
10,231,657 10,231,670			Al-Ali et al. Blank et al.	2007/0249910		11/2007	
10,231,676			Al-Ali et al.	2007/0293792	A1	12/2007	Sliwa et al.
RE47,353			Kiani et al.	2008/0004513			Walker et al.
10,251,585 10,251,586			Al-Ali et al. Lamego	2008/0015424 2008/0076980			Bernreuter Hoarau
10,251,380		4/2019	Sampath et al.	2008/0081966	A1	4/2008	Debreczeny
10,258,265	B1	4/2019	Poeze et al.	2008/0130232			Yamamoto
10,258,266			Poeze et al.	2008/0139908 2008/0190436		6/2008 8/2008	Jaffe et al.
10,271,748 10,278,626		4/2019 5/2019	Schurman et al.	2008/0221426			Baker et al.
10,278,648	B2		Al-Ali et al.	2008/0221463		9/2008	
10,279,247		5/2019		2009/0030327 2009/0043180			Chance Tschautscher et al.
10,292,628 10,292,657			Poeze et al. Abdul-Hafiz et al.	2009/0129102			Xiao et al.
10,292,664		5/2019		2009/0163775			Barrett et al.
10,299,708			Poeze et al.	2009/0177097 2009/0187085		7/2009	Ma et al.
10,299,709 10,305,775			Perea et al. Lamego et al.	2009/0234206			Gaspard et al.
10,307,111			Muhsin et al.	2009/0247885		10/2009	
10,325,681			Sampath et al.	2009/0247984 2009/0259114		10/2009 10/2009	Lamego et al. Johnson et al.
10,327,337 10,327,713			Triman et al. Barker et al.	2009/0239114		10/2009	
10,332,630		6/2019		2009/0275813		11/2009	
10,335,033		7/2019		2009/0275844 2009/0306487		11/2009	Al-Ali Crowe et al.
10,335,068 10,335,072			Poeze et al. Al-Ali et al.	2010/0004518			Vo et al.
10,342,470			Al-Ali et al.	2010/0030040			Poeze et al.
10,342,487	B2	7/2019	Al-Ali et al.	2010/0030043 2010/0113948		2/2010	Kuhn Yang et al.
10,342,497 10,349,895			Al-Ali et al. Telfort et al.	2010/0113948			Ozawa et al.
10,349,898			Al-Ali et al.	2010/0210925	A1	8/2010	Holley et al.
10,354,504			Kiani et al.	2010/0305416 2011/0001605			Bedard et al. Kiani et al.
10,357,206 10,357,209		7/2019 7/2019	Weber et al.	2011/0004079			Al-Ali et al.
10,366,787			Sampath et al.	2011/0004106	A1	1/2011	Iwamiya et al.
10,368,787	B2	8/2019	Reichgott et al.	2011/0082711 2011/0085721			Poeze et al.
10,376,190 10,376,191			Poeze et al. Poeze et al.	2011/0085721			Guyon et al. Kiani et al.
10,370,191			Wojtczuk et al.	2011/0105865	A1	5/2011	Yu et al.
10,383,527	B2	8/2019	Al-Ali	2011/0208015			Welch et al.
10,388,120			Muhsin et al.	2011/0213212 2011/0230733		9/2011 9/2011	
10,398,320 10,405,804		9/2019	Kiani et al. Al-Ali	2011/0237911			Lamego et al.
10,413,666	B2	9/2019	Al-Ali et al.	2012/0059267		3/2012	Lamego et al.
10,420,493			Al-Ali et al.	2012/0165629			Merritt et al.
10,433,776 10,441,181		10/2019 10/2019	Al-Alı Telfort et al.	2012/0179006 2012/0209084			Jansen et al. Olsen et al.
10,448,844			Al-Ali et al.	2012/0227739		9/2012	
10,448,871	B2	10/2019	Al-Ali	2012/0283524	A1	11/2012	Kiani et al.
10,456,038			Lamego et al.	2012/0296178			Lamego et al.
10,463,284 10,463,340			Al-Ali et al. Telfort et al.	2012/0319816 2012/0330112		12/2012	Al-Alı Lamego et al.
10,405,540	102	11/2019	Tonort et al.	2012/0330112	7 3 1	12/2012	Lamego et al.

Case: 22-1972 Document: 33-2 Page: 16 Filed: 05/11/2023

(56)	References Cited	2015/0094546 A1	4/2015 Al-Ali
U.S.	. PATENT DOCUMENTS	2015/0099950 A1 2015/0101844 A1	4/2015 Al-Ali et al. 4/2015 Al-Ali et al.
0.0.		2015/0106121 A1	4/2015 Muhsin et al.
2013/0023775 A1	1/2013 Lamego et al.	2015/0173671 A1 2015/0196249 A1	6/2015 Paalasmaa et al. 7/2015 Brown et al.
2013/0041591 A1 2013/0045685 A1	2/2013 Lamego 2/2013 Kiani	2015/0216459 A1	8/2015 Al-Ali et al.
2013/0046204 A1	2/2013 Klain 2/2013 Lamego et al.	2015/0238722 A1	8/2015 Al-Ali
2013/0060147 A1	3/2013 Welch et al.	2015/0255001 A1 2015/0257689 A1	9/2015 Haughav et al. 9/2015 Al-Ali et al.
2013/0096405 A1 2013/0096936 A1	4/2013 Garfio 4/2013 Sampath et al.	2015/0281424 A1	10/2015 Vock et al.
2013/0190581 A1	7/2013 Al-Ali et al.	2015/0318100 A1	11/2015 Rothkopf et al.
2013/0197328 A1	8/2013 Diab et al.	2015/0351697 A1 2015/0351704 A1	11/2015 Weber et al. 12/2015 Kiani et al.
2013/0211214 A1 2013/0243021 A1	8/2013 Olsen 9/2013 Siskavich	2015/0366472 A1	12/2015 Kiani et al. 12/2015 Kiani
2013/0296672 A1	11/2013 O'Neil et al.	2015/0366507 A1	12/2015 Blank
2013/0324808 A1	12/2013 Al-Ali et al.	2015/0374298 A1 2015/0380875 A1	12/2015 Al-Ali et al. 12/2015 Coverston et al.
2013/0331660 A1 2013/0331670 A1	12/2013 Al-Ali et al. 12/2013 Kiani	2016/0000362 A1	1/2016 Diab et al.
2013/0331070 A1 2013/0338461 A1	12/2013 Klain 12/2013 Lamego et al.	2016/0007930 A1	1/2016 Weber et al.
2014/0012100 A1	1/2014 Al-Ali et al.	2016/0019360 A1 2016/0023245 A1	1/2016 Pahwa et al. 1/2016 Zadesky et al.
2014/0034353 A1 2014/0051953 A1	2/2014 Al-Ali et al. 2/2014 Lamego et al.	2016/0023243 A1 2016/0029932 A1	2/2016 Al-Ali
2014/0051933 A1 2014/0058230 A1	2/2014 Abdul-Hafiz et al.	2016/0029933 A1	2/2016 Al-Ali et al.
2014/0077956 A1	3/2014 Sampath et al.	2016/0038045 A1 2016/0045118 A1	2/2016 Shapiro 2/2016 Kiani
2014/0081100 A1 2014/0081175 A1	3/2014 Muhsin et al. 3/2014 Telfort	2016/0043118 A1 2016/0051157 A1	2/2016 Kiani 2/2016 Waydo
2014/0081173 A1 2014/0094667 A1	4/2014 Tenort 4/2014 Schurman et al.	2016/0051158 A1	2/2016 Silva
2014/0100434 A1	4/2014 Diab et al.	2016/0051205 A1	2/2016 Al-Ali et al.
2014/0114199 A1	4/2014 Lamego et al. 5/2014 Workman et al.	2016/0058302 A1 2016/0058309 A1	3/2016 Raghuram et al. 3/2016 Han
2014/0120564 A1 2014/0121482 A1	5/2014 Workman et al. 5/2014 Merritt et al.	2016/0058312 A1	3/2016 Han et al.
2014/0121483 A1	5/2014 Kiani	2016/0058338 A1	3/2016 Schurman et al.
2014/0127137 A1	5/2014 Bellott et al.	2016/0058356 A1 2016/0058370 A1	3/2016 Raghuram et al. 3/2016 Raghuram et al.
2014/0129702 A1 2014/0135588 A1	5/2014 Lamego et al. 5/2014 Al-Ali et al.	2016/0066823 A1	3/2016 Al-Ali et al.
2014/0142401 A1	5/2014 Al-Ali et al.	2016/0066824 A1	3/2016 Al-Ali et al.
2014/0163344 A1	6/2014 Al-Ali	2016/0066879 A1 2016/0071392 A1	3/2016 Telfort et al. 3/2016 Hankey et al.
2014/0163402 A1 2014/0166076 A1	6/2014 Lamego et al. 6/2014 Kiani et al.	2016/0072429 A1	3/2016 Kiani et al.
2014/0171146 A1	6/2014 Ma et al.	2016/0073967 A1	3/2016 Lamego et al.
2014/0171763 A1	6/2014 Diab	2016/0095543 A1 2016/0103598 A1	4/2016 Telfort et al. 4/2016 Al-Ali et al.
2014/0180154 A1 2014/0180160 A1	6/2014 Sierra et al. 6/2014 Brown et al.	2016/0113527 A1	4/2016 Al-Ali et al.
2014/0187973 A1	7/2014 Brown et al.	2016/0143548 A1	5/2016 Al-Ali
2014/0194709 A1	7/2014 Al-Ali et al.	2016/0154950 A1 2016/0157780 A1	6/2016 Nakajima et al. 6/2016 Rimminen et al.
2014/0194711 A1 2014/0194766 A1	7/2014 Al-Ali 7/2014 Al-Ali et al.	2016/0166210 A1	6/2016 Al-Ali
2014/0206963 A1	7/2014 Al-Ali	2016/0192869 A1	7/2016 Kiani et al.
2014/0213864 A1	7/2014 Abdul-Hafiz et al. 8/2014 Diab et al.	2016/0196388 A1 2016/0197436 A1	7/2016 Lamego 7/2016 Barker et al.
2014/0243627 A1 2014/0266790 A1	9/2014 Diab et al. 9/2014 Al-Ali et al.	2016/0213281 A1	7/2016 Eckerbom et al.
2014/0275808 A1	9/2014 Poeze et al.	2016/0213309 A1	7/2016 Sannholm et al.
2014/0275871 A1	9/2014 Lamego et al.	2016/0228043 A1 2016/0256058 A1	8/2016 O'Neil et al. 9/2016 Pham et al.
2014/0275872 A1 2014/0275881 A1	9/2014 Merritt et al. 9/2014 Lamego et al.	2016/0256082 A1	9/2016 Ely et al.
2014/0288400 A1	9/2014 Diab et al.	2016/0267238 A1	9/2016 Nag
2014/0296664 A1 2014/0303520 A1	10/2014 Bruinsma et al. 10/2014 Telfort et al.	2016/0270735 A1 2016/0283665 A1	9/2016 Diab et al. 9/2016 Sampath et al.
2014/0316217 A1	10/2014 Tenori et al. 10/2014 Purdon et al.	2016/0287181 A1	10/2016 Han et al.
2014/0316218 A1	10/2014 Purdon et al.	2016/0287786 A1	10/2016 Kiani
2014/0316228 A1 2014/0323825 A1	10/2014 Blank et al. 10/2014 Al-Ali et al.	2016/0296173 A1 2016/0296174 A1	10/2016 Culbert 10/2016 Isikman et al.
2014/0323823 A1 2014/0323897 A1	10/2014 Al-All et al. 10/2014 Brown et al.	2016/0310027 A1	10/2016 Han
2014/0323898 A1	10/2014 Purdon et al.	2016/0314260 A1	10/2016 Kiani
2014/0330098 A1 2014/0330099 A1	11/2014 Merritt et al. 11/2014 Al-Ali et al.	2016/0324488 A1 2016/0327984 A1	11/2016 Olsen 11/2016 Al-Ali et al.
2014/0333440 A1	11/2014 Al-Ali et al. 11/2014 Kiani	2016/0367173 A1	12/2016 Dalvi et al.
2014/0336481 A1	11/2014 Shakespeare et al.	2016/0378069 A1	12/2016 Rothkopf
2014/0343436 A1	11/2014 Kiani 12/2014 Al-Ali et al.	2016/0378071 A1 2017/0007183 A1	12/2016 Rothkopf 1/2017 Dusan et al.
2014/0357966 A1 2015/0005600 A1	1/2014 Al-All et al. 1/2015 Blank et al.	2017/0007183 A1 2017/0010858 A1	1/2017 Dusan et al.
2015/0011907 A1	1/2015 Purdon et al.	2017/0014083 A1	1/2017 Diab et al.
2015/0018650 A1	1/2015 Al-Ali et al.	2017/0024748 A1	1/2017 Haider
2015/0032029 A1 2015/0038859 A1	1/2015 Al-Ali et al. 2/2015 Dalvi et al.	2017/0042488 A1 2017/0055896 A1	2/2017 Muhsin 3/2017 Al-Ali et al.
2015/0038839 A1 2015/0073235 A1	3/2015 Kateraas et al.	2017/0033890 A1 2017/0074897 A1	3/2017 Al-All et al. 3/2017 Mermel et al.
2015/0080754 A1	3/2015 Purdon et al.	2017/0084133 A1	3/2017 Cardinali et al.
2015/0087936 A1	3/2015 Al-Ali et al.	2017/0086689 A1	3/2017 Shui et al.
		0	

Case: 22-1972 Document: 33-2 Page: 17 Filed: 05/11/2023

(56)	References Cited	2018/0206815 A1 2018/0213583 A1	7/2018 7/2018	
U.S.	PATENT DOCUMENTS	2018/0214090 A1		Al-Ali et al.
		2018/0216370 A1		Ishiguro et al.
2017/0086742 A1	3/2017 Harrison-Noonan et al.	2018/0218792 A1 2018/0225960 A1		Muhsin et al. Al-Ali et al.
2017/0086743 A1 2017/0094450 A1	3/2017 Bushnell et al. 3/2017 Tu et al.	2018/0228414 A1	8/2018	
2017/0143281 A1	5/2017 Olsen	2018/0238718 A1	8/2018	
2017/0147774 A1	5/2017 Kiani	2018/0238734 A1 2018/0242853 A1	8/2018 8/2018	Hotelling et al. Al-Ali
2017/0156620 A1 2017/0164884 A1	6/2017 Al-Ali et al. 6/2017 Culbert et al.	2018/0242933 A1 2018/0242921 A1	8/2018	Muhsin et al.
2017/0104884 A1 2017/0173632 A1	6/2017 Culbert et al. 6/2017 Al-Ali	2018/0242923 A1		Al-Ali et al.
2017/0196464 A1	7/2017 Jansen et al.	2018/0242926 A1 2018/0247353 A1		Muhsin et al. Al-Ali et al.
2017/0196470 A1 2017/0228516 A1	7/2017 Lamego et al. 8/2017 Sampath et al.	2018/0247333 A1 2018/0247712 A1		Muhsin et al.
2017/0228310 A1 2017/0245790 A1	8/2017 Sampan et al.	2018/0256087 A1	9/2018	Al-Ali et al.
2017/0248446 A1	8/2017 Gowreesunker et al.	2018/0279956 A1 2018/0285094 A1		Waydo et al. Housel et al.
2017/0251974 A1 2017/0251975 A1	9/2017 Shreim et al. 9/2017 Shreim et al.	2018/0289325 A1	10/2018	Poeze et al.
2017/0231973 A1 2017/0273619 A1	9/2017 Shienn et al. 9/2017 Alvarado et al.	2018/0296161 A1	10/2018	Shreim et al.
2017/0281024 A1	10/2017 Narasimhan et al.	2018/0300919 A1		Muhsin et al. Indorf et al.
2017/0293727 A1 2017/0311891 A1	10/2017 Klaassen et al. 11/2017 Kiani et al.	2018/0310822 A1 2018/0310823 A1		Al-Ali et al.
2017/0311891 A1 2017/0325698 A1	11/2017 Riam et al. 11/2017 Allec et al.	2018/0317826 A1	11/2018	Muhsin
2017/0325744 A1	11/2017 Allec et al.	2018/0317841 A1		Novak, Jr.
2017/0340209 A1 2017/0340219 A1	11/2017 Klaassen et al. 11/2017 Sullivan et al.	2018/0333055 A1 2018/0333087 A1	11/2018	Lamego et al. Al-Ali
2017/0340219 A1 2017/0340293 A1	11/2017 Sunivan et al. 11/2017 Al-Ali et al.	2019/0000317 A1	1/2019	Muhsin et al.
2017/0347885 A1	12/2017 Tan et al.	2019/0000362 A1 2019/0015023 A1		Kiani et al.
2017/0354332 A1	12/2017 Lamego	2019/0015023 A1 2019/0029574 A1	1/2019 1/2019	Monfre Schurman et al.
2017/0354795 A1 2017/0358239 A1	12/2017 Blahnik et al. 12/2017 Arney et al.	2019/0029578 A1	1/2019	Al-Ali et al.
2017/0358240 A1	12/2017 Blahnik et al.	2019/0058280 A1	2/2019 2/2019	
2017/0358242 A1	12/2017 Thompson et al.	2019/0058281 A1 2019/0069813 A1	3/2019	Al-Ali et al. Al-Ali
2017/0360306 A1 2017/0360310 A1	12/2017 Narasimhan et al. 12/2017 Kiani et al.	2019/0076028 A1	3/2019	Al-Ali et al.
2017/0366657 A1	12/2017 Thompson et al.	2019/0082979 A1	3/2019	
2018/0008146 A1	1/2018 Al-Ali et al.	2019/0090760 A1 2019/0090764 A1	3/2019 3/2019	Kinast et al. Al-Ali
2018/0013562 A1 2018/0014752 A1	1/2018 Haider et al. 1/2018 Al-Ali et al.	2019/0117070 A1	4/2019	Muhsin et al.
2018/0014781 A1	1/2018 Clavelle et al.	2019/0117139 A1	4/2019	Al-Ali et al.
2018/0025287 A1	1/2018 Mathew et al.	2019/0117141 A1 2019/0117930 A1	4/2019 4/2019	Al-Ali Al-Ali
2018/0028124 A1 2018/0042556 A1	2/2018 Al-Ali et al. 2/2018 Shahparnia et al.	2019/0122763 A1	4/2019	Sampath et al.
2018/0049694 A1	2/2018 Singĥ Alvarado et al.	2019/0133525 A1	5/2019	Al-Ali et al.
2018/0050235 A1 2018/0055375 A1	2/2018 Tan et al. 3/2018 Martinez et al.	2019/0142283 A1 2019/0142344 A1	5/2019 5/2019	Lamego et al. Telfort et al.
2018/0055390 A1	3/2018 Martinez et al. 3/2018 Kiani	2019/0150856 A1	5/2019	
2018/0055430 A1	3/2018 Diab et al.	2019/0167161 A1	6/2019	Al-Ali et al.
2018/0055439 A1 2018/0056129 A1	3/2018 Pham et al. 3/2018 Narasimha Rao et al.	2019/0175019 A1 2019/0192076 A1	6/2019 6/2019	Al-Ali et al. McHale et al.
2018/0030129 A1 2018/0064381 A1	3/2018 Natasimila Rao et al.	2019/0200941 A1	7/2019	Chandran et al.
2018/0070867 A1	3/2018 Smith et al.	2019/0201623 A1	7/2019	
2018/0078151 A1 2018/0078182 A1	3/2018 Allec et al. 3/2018 Chen et al.	2019/0209025 A1 2019/0214778 A1	7/2019 7/2019	Scruggs et al.
2018/0078182 A1 2018/0082767 A1	3/2018 Cheff et al. 3/2018 Al-Ali et al.	2019/0216319 A1	7/2019	Poeze et al.
2018/0085068 A1	3/2018 Telfort	2019/0216379 A1 2019/0221966 A1		Al-Ali et al. Kiani et al.
2018/0087937 A1 2018/0103874 A1	3/2018 Al-Ali et al. 4/2018 Lee et al.	2019/0223804 A1		Blank et al.
2018/01039/4 A1 2018/0103905 A1	4/2018 Eee et al. 4/2018 Kiani	2019/0231199 A1	8/2019	Al-Ali et al.
2018/0110469 A1	4/2018 Maani et al.	2019/0231241 A1 2019/0231270 A1	8/2019 8/2019	Al-Ali et al. Abdul-Hafiz et al.
2018/0125368 A1 2018/0125430 A1	5/2018 Lamego et al. 5/2018 Al-Ali et al.	2019/0231270 A1 2019/0239787 A1		Pauley et al.
2018/0125445 A1	5/2018 Telfort et al.	2019/0239824 A1	8/2019	Muhsin et al.
2018/0132769 A1	5/2018 Weber et al.	2019/0254578 A1 2019/0261857 A1	8/2019 8/2019	Lamego
2018/0146901 A1 2018/0146902 A1	5/2018 Al-Ali et al. 5/2018 Kiani et al.	2019/0261837 A1 2019/0269370 A1		Al-Ali et al.
2018/0153418 A1	6/2018 Sullivan et al.	2019/0274627 A1	9/2019	Al-Ali et al.
2018/0153442 A1	6/2018 Eckerbom et al.	2019/0274635 A1		Al-Ali et al.
2018/0153446 A1 2018/0153448 A1	6/2018 Kiani 6/2018 Weber et al.	2019/0290136 A1 2019/0298270 A1	10/2019	Dalvi et al. Al-Ali et al.
2018/0153448 A1 2018/0164853 A1	6/2018 Weber et al. 6/2018 Myers et al.	2019/0298270 A1 2019/0304601 A1	10/2019	Sampath et al.
2018/0168491 A1	6/2018 Al-Ali et al.	2019/0304605 A1	10/2019	Al-Ali
2018/0184917 A1	7/2018 Kiani	2019/0307377 A1		Perea et al.
2018/0192924 A1 2018/0192953 A1	7/2018 Al-Ali 7/2018 Shreim et al.	2019/0320906 A1 2019/0320959 A1	10/2019 10/2019	
2018/0196514 A1	7/2018 Allec et al.	2019/0320939 A1 2019/0320988 A1	10/2019	Ahmed et al.
2018/0199871 A1	7/2018 Pauley et al.	2019/0325722 A1		Kiani et al.
2018/0206795 A1	7/2018 Al-Ali	2019/0350506 A1	11/2019	Al-Ali

### US 10,624,564 B1

Page 11

#### (56)References Cited OTHER PUBLICATIONS U.S. PATENT DOCUMENTS Jan. 9, 2020 Complaint for (1) Patent Infringement (2) Trade Secret Misappropriation and (3) Ownership of Patents and Demand for 11/2019 Poeze et al. 2019/0357812 A1 Jury Trial, Masimo Corporation and Cercacor Laboratories, Inc. v. 2019/0357813 A1 11/2019 Poeze et al. Apple Inc., Case No. 8:20-cv-00048, 64 pages. 2019/0365294 A1 12/2019 Poeze et al. U.S. Appl. No. 12/534,827, Multi-Stream Data Collection System 12/2019 Poeze et al. 2019/0365295 A1 for Noninvasive Measurement of Blood Constituents, filed Aug. 3, 2019/0374135 A1 12/2019 Poeze et al. U.S. Appl. No. 16/449,143, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Jun. 21, FOREIGN PATENT DOCUMENTS U.S. Appl. No. 16/534,956, Multi-Stream Data Collection System EΡ 419223 3/1991 for Noninvasive Measurement of Blood Constituents, filed Aug. 7, EΡ 0630208 A1 12/1994 ΕP 0 781 527 7/1997 U.S. Appl. No. 16/534,949, Multi-Stream Data Collection System 0880936 A2 12/1998 ΕP for Noninvasive Measurement of Blood Constituents, filed Aug. 7, ΕP 0922432 A1 6/1999 EP 0985373 A1 3/2000 U.S. Appl. No. 16/541,987, Multi-Stream Data Collection System EP1 518 494 3/2005 for Noninvasive Measurement of Blood Constituents, filed Aug. 15, EΡ 1526805 A1 5/2005 ΕP 1124609 B1 8/2006 U.S. Appl. No. 16/544,713, Multi-Stream Data Collection System 1860989 A1 EP 12/2007 for Noninvasive Measurement of Blood Constituents, filed Aug. 19, ΕP 1875213 A2 1/2008 EP1880666 A1 1/2008 U.S. Appl. No. 16/544,755, Multi-Stream Data Collection System 2165196 A1 EP3/2010 for Noninvasive Measurement of Blood Constituents, filed Aug. 19, EΡ 2 277 440 1/2011 2243691 A 11/1991 GΒ U.S. Appl. No. 16/594,980, Multi-Stream Data Collection System 05-325705 A JΡ 12/1993 for Noninvasive Measurement of Blood Constituents, filed Oct. 7, JΡ 08-185864 7/1996 JΡ H 09257508 A 10/1997 U.S. Appl. No. 16/725,478, Multi-Stream Data Collection System JΡ H 10314133 A 12/1998 JΡ 3/1999 for Noninvasive Measurement of Blood Constituents, filed Dec. 23, H 1170086 A JР 2919326 B2 7/1999 JΡ U.S. Appl. No. 14/064,055, Multi-Stream Sensor for Noninvasive H 11235320 A 8/1999 JР 3/2001 Measurement of Blood Constituents, filed Oct. 25, 2013. 2001-66990 JР 2001-087250 A 4/2001 U.S. Appl. No. 15/660,743, Noise Shielding for a Noninvasive JΡ 2002-500908 A Device, filed Jul. 26, 2017. 1/2002 JР 2003-024276 A 1/2003 U.S. Appl. No. 12/497,506, Heat Sink for Noninvasive Medical JР 2003-508104 A 3/2003 Sensor, filed Jul. 2, 2009 JΡ 2003-265444 A 9/2003 U.S. Appl. No. 15/195,199, Advanced Pulse Oximetry Sensor, filed JΡ 2004329406 A 11/2004 Jun. 28, 2016. JР 2005160641 A 6/2005 U.S. Appl. No. 16/226,249, Advanced Pulse Oximetry Sensor, filed JР 2005270543 A 10/2005 Dec. 19, 2018. JР 3741147 B2 2/2006 U.S. Appl. No. 16/532,061, Advanced Pulse Oximetry Sensor, filed JР 2006102164 A 4/2006 Aug. 5, 2019. JΡ 2006-177837 A 7/2006 U.S. Appl. No. 16/532,065, Advanced Pulse Oximetry Sensor, filed JР 2006-198321 A 8/2006 Aug. 5, 2019. JР 38033851 B2 8/2006 PCT International Search Report, App. No. PCT/US2010/047899, JΡ 2007-389463 A 11/2007 dated Jan. 26, 2011, 4 pages. JР 2007319232 A 12/2007 International Search Report and Written Opinion for PCT/US2009/ JΡ 2008-099222 A 4/2008 049638, dated Jan. 7, 2010. JΡ 5756752 6/2015 International Search Report issued in Application No. PCT/US2009/ KR 20070061122 A 6/2007 052756, dated Feb. 10, 2009 in 14 pages. 100755079 B1 9/2007 KR International Preliminary Report on Patentability and Written Opin-WO 1993/12712 WO 7/1993 ion of the International Searching Authority issued in Application WO WO 94/23643 A1 10/1994 No. PCT US2009/049638, dated Jan. 5, 2011 in 9 pages. WO WO 1995/000070 A1 1/1995 International Preliminary Report on Patentability and Written Opin-WO 1996/27325 WO 9/1996 ion of the International Searching Authority issued in Application WO WO 1997/009923 A1 3/1997 No. PCT/US2009/052756, dated Feb. 8, 2011 in 8 pages. WO 0770349 A1 5/1997 International Preliminary Report on Patentability and Written Opin-1/1999 WO WO 1999/000053 ion for International Application No. PCT/US2016/040190, dated WO WO 1999/01704 7/1999 Jan. 2, 2018, in 7 pages. WO WO 1999/063883 A1 12/1999 Burritt, Mary F.; Current Analytical Approaches to Measuring WO 5/2000 WO 2000/25112 Blood Analytes; vol. 36; No. 8(B); 1990. WO WO 2000/028892 A1 5/2000 Hall, et al., Jeffrey W.; Near-Infrared Spectrophotometry: A New WO WO 2001/09589 2/2001 Dimension in Clinical Chemistry; vol. 38; No. 9; 1992 WO WO 2006/060949 A1 6/2006 Kuenstner, et al., J. Todd; Measurement of Hemoglobin in Unlysed WO WO 2006/079862 A2 8/2006 Blood by Near-Infrared Spectroscopy; vol. 48; No. 4, 1994. WO WO 2006/090371 A2 8/2006 WO WO 2007/004083 A1 1/2007 Manzke, et al., B., Multi Wavelength Pulse Oximetry in the Measurement of Hemoglobin Fractions; SPIE, vol. 2676, Apr. 24, 1996. WO WO 2007/017266 A2 2/2007 WO WO 2008/107238 A1 9/2008 Naumenko, E. K.; Choice of Wavelengths for Stable Determination WO WO 2010/003134 1/2010 of Concentrations of Hemoglobin Derivatives from Absorption WO WO 2014/149781 9/2014 Spectra of Erythrocytes; vol. 63; No. 1; pp. 60-66 Jan.-Feb. 1996;

Original article submitted Nov. 3, 1994.

WO

WO 2014/158820

10/2014

Case: 22-1972 Document: 33-2 Page: 19 Filed: 05/11/2023

### US 10,624,564 B1

Page 12

#### (56)References Cited

### OTHER PUBLICATIONS

Schmitt, Joseph M.; Simple Photon Diffusion Anaylsis of the Effects of Multiple Scattering on Pulse Oximetry; Mar. 14, 1991; revised Aug. 30, 1991.

Schmitt, et al., Joseph M.; Measurement of Blood Hematocrit by Dual-Wavelength near-IR Photoplethysmography; vol. 1641; 1992. Schnapp, et al., L.M.; Pulse Oximetry. Uses and Abuses.; Chest 1990; 98; 1244-1250 DOI 10.1378/Chest.98.5.1244.

http://www.masimo.com/rainbow/pronto.htm Noninvasive & Immediate Hemoglobin Testing, printed on Aug. 20, 2009.

http://www.masimo.com/pulseOximeter/Rad5.htm; Signal Extraction Pulse Oximeter, printed on Aug. 20, 2009.

http://blogderoliveira.blogspot.com/2008\_02\_01\_archive.html; Ricardo Oliveira, printed on Aug. 20, 2009.

http://www.masimo.com/rad-57/; Noninvasive Measurement of Methemoglobin, Carboxyhemoglobin and Oxyhemoglobin in the blood. Printed on Aug. 20, 2009.

http://amivital.ugr.es/blog/?tag+spo2; Monitorizacion de la hemoglobina . . . y mucho mas, printed on Aug. 20, 2009

http://www.masimo.com/spco/; Carboxyhemoglobin Noninvasive > Continuous > Immediate, printed on Aug. 20, 2009.

http://www.masimo.com/PARTNERS/WELCHALLYN.htm; Welch Allyn Expands Patient Monitor Capabilities with Masimo Pulse Oximetry Technology, printed on Aug. 20, 2009.

http://www.masimo.com/pulseOximeter/PPO.htm; Masimo Personal Pulse Oximeter, printed on Aug. 20, 2009.

http://www.masimo.com/generalFloor/system.htm; Masimo Patient SafetyNet System at a Glance, printed on Aug. 20, 2009.

http://www.masimo.com/partners/GRASEBY.htm; Graseby Medical Limited, printed on Aug. 20, 2009.

Japanese Office Action, re JP Application No. 2011-516895, dated Sep. 2, 2014, with translation.

Japanese Notice of Allowance, re JP Application No. 2011-516895, dated May 12, 2015, no translation.

European Office Action issued in application No. 10763901.5 dated

European Office Action issued in application No. 10763901.5 dated Aug. 27, 2014.

European Office Action issued in application No. 10763901.5 dated Aug. 6, 2015.

European Office Action issued in Application No. 09791157.2, dated Jun. 20, 2016.

Kanukurthy et al., "Data Acquisition Unit for an Implantable Multi-Channel Optical Glucose Sensor", Electro/Information Technology Conference, Chicago, IL, USA, May 17-20, 2007, pp. 1-6. Konig et al., "Reflectance Pulse Oximetry-Principles and Obstetric Application in the Zurich System", Journal of Clinical Monitoring and Computing, vol. 14, No. 6, Aug. 1998, pp. 403-412.

Smith, "The Pursuit of Noninvasive Glucose: 'Hunting the Deceitful Turkey", 2006.

Small et al., "Data Handling Issues for Near-Infrared Glucose Measurements", http://www.ieee.org/organizations/pubs/newsletters/ leos/apr98/datahandling.htm, accessed Nov. 27, 2007.

D. C. Zheng and Y. T. Zhang, "A ring-type device for the noninvasive measurement of arterial blood pressure," Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No. 03CH37439), Sep. 17-21, 2003, Cancun, pp. 3184-3187 vol. 4.

Sokwoo Rhee et al., "Artifact-Resistant Power-Efficient Design of Finger-Ring Plethysmographic Sensors," IEEE Transactions on Biomedical Engineering, Jul. 2001, pp. 795-805, vol. 48, No. 7.

L. Xu et al., "An integrated wrist-worn routine monitoring system for the elderly using BSN," 2008 5th International Summer School and Symposium on Medical Devices and Biosensors, Hong Kong, 2008, pp. 45-48.

J Kraitl et al., "An optical device to measure blood components by a photoplethysmographic method," Journal of Optics A: Pure and Applied Optics. 7, 2005, pp. S318-S324.

K. Nakajima et al., "Monitoring of heart and respiratory rates by photoplethysmography using digital filtering technique," Med. Eng. Phy. vol. 18, No. 5, pp. 365-372, 1996.

Russell Dresher, "Wearable Forehead Pulse Oximetry: Minimization of Motion and Pressure Artifacts," May 3, 2006, 93 pages.

Sonnia Maria López Silva et al., "Near-infrared transmittance pulse oximetry with laser diodes," Journal of Biomedical Optics vol. 8 No. 3, Jul. 2003, pp. 525-533.

Fabio Buttussi et al., "MOPET: A context-aware and user-adaptive wearable system for fitness training," Artificial Intelligence in Medicine 42, 2008, pp. 153-163.

Stephen A. Mascaro et al., "Photoplethysmograph Fingernail Sensors for Measuring Finger Forces Without Haptic Obstruction," IEEE Transactions on Robotics and Automation, vol. 17, No. 5, Oct. 2001, pp. 698-708.

Stephen A. Mascaro et al., "Measurement of Finger Posture and Three-Axis Fingertip Touch Force Using Fingernail Sensors," IEEE International Conference on Robotics and Automation, 2002, pp. 1-11.

Akira Sakane et al., "Estimating Arterial Wall Impedance using a Plethysmogram," IEEE 2003, pp. 580-585.

Nuria Oliver et al., "HealthGear: A Real-time Wearable System for Monitoring and Analyzing Physiological Signals," Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks 2006 IEEE, pp. 1-4.

Yuan-Hsiang Lin et al., "A wireless PDA-based physiological monitoring system for patient transport," IEEE Transactions on Information Technology in Biomedicine, vol. 8, No. 4, pp. 439-447, Dec. 2004.

R. Fensli et al., "A Wireless ECG System for Continuous Event Recording and Communication to a Clinical Alarm Station," Conf Proc IEEE Eng Med Biol Soc, 2004, pp. 1-4.

E. Higurashi et al., "An integrated laser blood flowmeter," Journal of Lightwave Technology, vol. 21, No. 3, pp. 591-595, Mar. 2003. T. Kiyokura et al., "Wearable Laser Blood Flowmeter for Ubiquitous Healthcare Service," 2007 IEEE/LEOS International Conference on Optical MEMS and Nanophotonics, Hualien, 2007, pp. 4-5.

Takumi Morita et al., "Integrated Blood Flowmeter Using Micromachining Technology," Dec. 2004, pp. 77-80.

Eiji Higurashi et al., "Hybrid integration technologies for optical micro-systems", Proc. SPIE 5604, Optomechatronic Micro/Nano Components, Devices, and Systems, Oct. 25, 2004, pp. 67-73.

L. Grajales et al., "Wearable multisensor heart rate monitor," International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06), Cambridge, MA, 2006, pp. 4-157. N. Townsend, "Pulse Oximetry," Medical Electronics, 2001, pp.

32-42.

Nonin Medical, Inc., "Operator's Manual-Models 8600F0 and 8600F0M Pulse Oximeters," 2005, 25 pages.

C. J. Pujary, "Investigation of Photodetector Optimization in Reducing Power Consumption by a Noninvasive Pulse Oximeter Sensor," Worcester Polytechnic Institute, Jan. 16, 2004, 133 pages.

B. McGarry et al., "Reflections on a candidate design of the user-interface for a wireless vital-signs monitor," Proceedings of DARE 2000 on Designing Augmented Reality Environments, Jan. 2000, pp. 33-40.

J. C. D. Conway et al., "Wearable computer as a multi-parametric monitor for physiological signals," Proceedings IEEE International Symposium on Bio-Informatics and Biomedical Engineering, Arlington, VA, USA, 2000, pp. 236-242.

J. A. Tamada et al., "Noninvasive Glucose Monitoring: Comprehensive Clinical Results," JAMA, Nov. 17, 1999, vol. 282, No. 19, pp. 1839-1844.

B.-H. Yang et al., "Development of the ring sensor for healthcare automation," Robotics and Autonomous Systems, 2000, pp. 273-

Laukkanen RM et al., "Heart Rate Monitors: State of the Art," Journal of Sports Science, Jan. 1998, pp. S3-S7.

S. Warren et al., "Designing Smart Health Care Technology into the Home of the Future," Workshops on Future Medical Devices: Home Care Technologies for the 21st Century, Apr. 1999, 19 pages.

### US 10,624,564 B1

Page 13

### (56) References Cited

### OTHER PUBLICATIONS

- A. C. M. Dassel et al., "Reflectance Pulse Oximetry at the Forehead Improves by Pressure on the Probe," Journal of Clinical Monitoring, vol. 11, No. 4, Jul. 1995, pp. 237-244.
- B-H. Yang et al., "A Twenty-Four Hour Tele-Nursing System Using a Ringer Sensor," Proceedings of 1998 IEEE International Conference on Robotics and Automation, May 16-20, 1998, 6 pages.
- S. Rhee et al., "The Ring Sensor: a New Ambulatory Wearable Sensor for Twenty-Four Hour Patient Monitoring," Proceedings of the 20<sup>th</sup> Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Oct. 29-Nov. 1 1998, 4 pages. Rhee et al., "Design of a Artifact-Free Wearable Plethysmographic Sensor," 21<sup>st</sup> Annual International Conference IEEE Engineering in Medicine and Biology Society, Oct. 13-16, 1999, p. 786.
- T. Martin et al., "Issues in Wearable Computing for Medical Montioring Applications: A Case Study of a Wearable ECG Monitoring Device," In Proceedings of International Symposium of Wearable Computers (ISWC'00), Feb. 2000, pp. 43-49.
- S. Rhee et al., "Artifact-Resistant, Power Efficient Design of Finger-Ring Plethysmographic Sensors, Part I: Design and Analysis," 22<sup>nd</sup> Annual International Conference IEEE Engineering in Medicine and Biology Society, Jul. 23-28, 2000, pp. 2792-2795.
- C. Pujary et al., "Photodetector Size Considerations in the Design of a Noninvasive Reflectance Pulse Oximeter for Telemedicine Applications," Proceedings of IEEE Annual Northeast Bioengineering Conference, 2003, pp. 148-149.
- M. Savage et al., "Optimizing Power Consumption in the Design of a Wearable Wireless Telesensor: Comparison of Pulse Oximeter Modes," Proceedings of IEEE 29<sup>th</sup> Annual Nonheust Bioengineering Conference, 2003, pp. 150-151.
- A. Tura et al., "A Wearable Device with Wireless Bluetooth-based Data Transmission," Measurement Science Review, vol. 3, Sec. 2, 2003, pp. 1-4.
- R. Paradiso, "Wearable Health Care System for Vital Signs Monitoring," In Proceedings of IEEE International Conference on Information Technology Applications in Biomedicine, May 2003, pp. 283-286.
- H.H. Asada et al., "Mobile Monitoring with Wearable Photoplethysmographic Biosensors," IEEE Engineering in Medicine and Biology Magazine, May/Jun. 2003, pp. 28-40.
- Y. Mendelson et al., "Minimization of LED Power Consumption in the Design of a Wearable Pulse Oximeter," Proceedings of the IASTED International Conference Biomedical Engineering, Jun. 25-27, 2003, 6 pages.
- Y. Mendelson et al., "Measurement Site and Photodetector Size Considerations in Optimizing Power Consumption of a Wearable Reflectance Pulse Oximeter," Proceedings of the 25<sup>th</sup> Annual International Conference of the IEEE EMBS, Sep. 17-21, 2003, pp. 3016-3019.
- D. Marculescu et al., "Ready to Ware," IEEE Spectrum, vol. 40, Issue 10, Oct. 2003, pp. 28-32.
- P. Celka et al., "Motion Resistant Earphone Located Infrared Based Hearth Rate Measurement Device," In Proceeding of the 2<sup>nd</sup> International Conference on Biomedical Engineering, Innsbruck, Austria, Feb. 16-18, 2004, pp. 582-585.
- D. Konstantas et al., "Mobile Patient Monitoring: The MobiHealth System," In Proceedings of International Conference on Medical and Care Compunetics, NCC'04, Feb. 2004, 8 pages.
- S. Pentland, "Healthwear: Medical Technology Becomes Wearable," IEEE Computer Society, vol. 37, Issue 5, May 2004, pp. 34-41.
- P. Branche et al., "Signal Quality and Power Consumption of a New Prototype Reflectance Pulse Oximeter Sensor," Proceeding of the 31th Annual Northeast Bioengineering Conference, Hoboken, NJ, IEEE, 2005, pp. 1-2.
- U. Anliker et al., "AMON: A Wearable Multiparameter Medical Monitoring and Alert System," IEEE Transactions on Information Technology in Biomedicine, Jan. 2005, pp. 1-11.
- P. T. Gibbs et al., "Active Motion Artifact Cancellation for Wearable Health Monitoring Sensors Using Collocated MEMS Accelerom-

- eters," Proceedings of SPIE Smart Structures and Materials: Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems, May 17, 2005, pp. 811-819.
- C. W. Mundt et al., "A Multiparameter Wearable Physiologic Monitoring System for Space and Terrestrial Applications," IEEE Transactions on Information Technology in Biomedicine, vol. 9, No. 3, Sep. 2005, pp. 382-391.
- Y. Mendelson et al., "A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 912-915.
- B-S. Lin et al., "RTWPMS: A Real-Time Wireless Physiological Monitoring System," IEEE Transactions on Information Technology in Biomedicine, vol. 10, No. 4, Oct. 2006, pp. 647-656.
- T. Torfs et al., "Body-Heat Powered Autonomous Pulse Oximeter," IEEE Sensors 2006, EXCO, Oct. 22-25, 2006, pp. 427-430.
- P.S. Pandian et al., "Smart Vest: Wearable Multi-Parameter Remote Physiological Monitoring System," Medical Engineering & Physics 30, 2008. pp. 466-477.
- G. Tamannagari, "Power Efficient Design of Finder-Ring Sensor for Patient Monitoring," Master of Science in Electrical Engineering, The University of Texas at San Antonio, College of Engineering, Department of Electrical Engineering, Dec. 2008, 74 pages.
- M. Yamashita et al., "Development of a Ring-Type Vital Sign Telemeter," Biotelemetry XIII, Mar. 26-31, 1995, pp. 145-150.
- P. Renevey et al., "Wrist-Located Pulse Detection Using IR Signals, Activity and Nonlinear Artifact Cancellation," Proceedings of the 23<sup>rd</sup> Annual EMBS International Conference, Oct. 25-28, 2001, pp. 3030-3033.
- Y. Mendelson et al., "A Mobile PDA-Based Wireless Pulse Oximeter," Proceedings of the IASTED International Conference Telehealth, Jul. 19-21, 2005, pp. 1-6.
- P. Shaltis et al., "Novel Design for a Wearable, Rapidly Depolyable, Wireless Noninvasive Triage Sensor," Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27<sup>th</sup> Annual Conference, Sep. 1-4, 2005, pp. 3567-3570.
- Y-S. Yan et al., An Efficient Motion-Resistant Method for Wearable Pulse Oximeter, IEEE Transactions on Information Technology in Biomedicine, vol. 12, No. 3, May 2008, pp. 399-405.
- P. C. Branche et al., "Measurement Reproducibility and Sensor Placement Considerations in Designing a Wearable Pulse Oximeter for Military Applications," IEEE, 2004, pp. 216-217.
- G. Comtois, "A Comparative Evaluation of Adaptive Noise Cancellation Algorithms for Minimizing Motion Artifacts in a Forehead-Mounted Wearable Pulse Oximeter," Proceedings of the 29<sup>th</sup> Annual international Conference of the IEEE EMBS, Aug. 23-26, 2007, pp. 1528-1531.
- G. Comtois et al., "A Noise Reference Input to an Adaptive Filter Algorithm for Signal Processing in a Wearable Pulse Oximeter," IEEE, 2007, pp. 106-107.
- R. P. Dresher et al., "A New Reflectance Pulse Oximeter Housing to Reduce Contact Pressure Effects," IEEE, 2006, pp. 49-50.
- R. P. Dresher et al., "Reflectance Forehead Pulse Oximetry: Effects on Contact Pressure During Walking," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 3529-3532.
- W. S. Johnston et al., "Extracting Breathing Rate Information from a Wearable Reflectance Pulse Oximeter Sensor," Proceedings of the 26<sup>th</sup> Annual International Conference of the IEEE EMBS, Sep. 1-5, 2004, pp. 5388-5391.
- W. Johnston et al., "Extracting Heart Rate Variability from a Wearable Reflectance Pulse Oximeter," IEEE, 2005, pp. 1-2.
- W. S. Johnston et al., "Investigation of Signal Processing Algorithms for an Embedded Microcontroller-Based Wearable Pulse Oximeter," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 5888-5891.
- P. Lukowicz et al., "AMON: A Wearable Medical Computer for High Risk Patient," Proceedings of the 6<sup>th</sup> International Symposium on Wearable Computers (ISWC'02), 2002, pp. 1-2.
- P. Lukowicz et al., "The WearARM Modular, Low-Power Computing Core," IEEE Micro, May-Jun. 2001, pp. 16-28.

### US 10,624,564 B1

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### (56) References Cited

### OTHER PUBLICATIONS

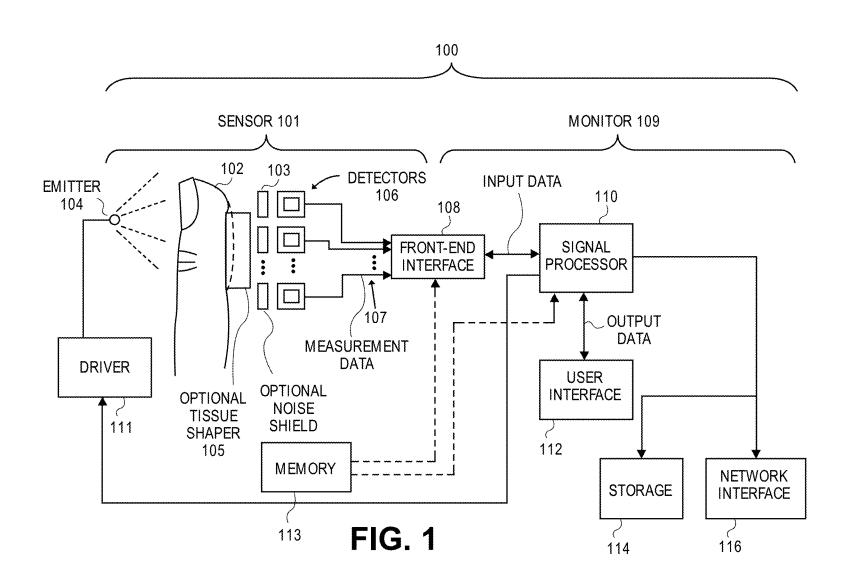
Y. Mendelson et al., "Accelerometery-Based Adaptive Noise Cancellation for Remote Physiological Monitoring by a Wearable Pulse Oximeter," Proceedings of the  $3^{rd}$  IASTED International Conference TELEHEALTH, May 31-Jun. 1, 2007, pp. 28-33.

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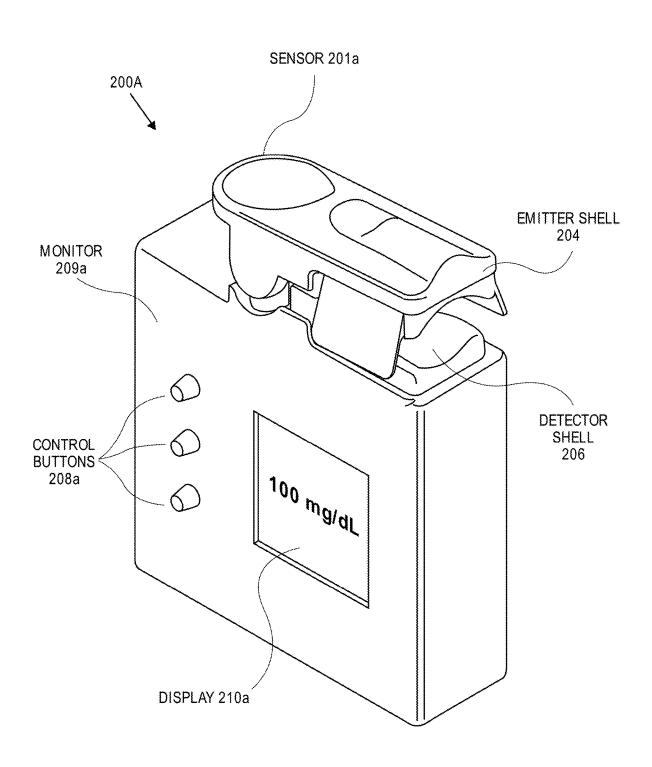


FIG. 2A

U.S. Patent Apr. 21, 2020 US 10,624,564 B1 Sheet 3 of 65 CABLE 212 205 4730 130 100 100 100 MONITOR 209b DISPLAY 210a

17 **Appx00326** 

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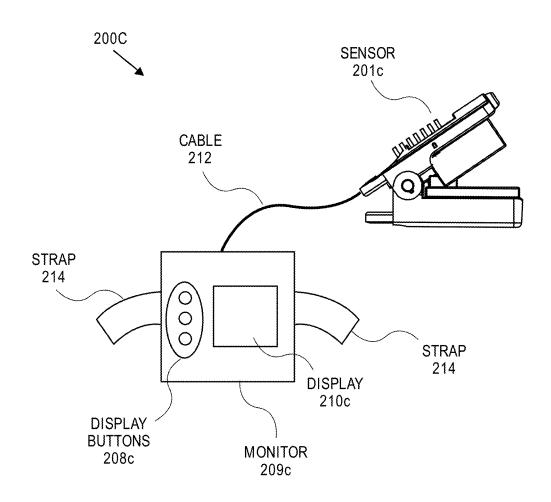


FIG. 2C

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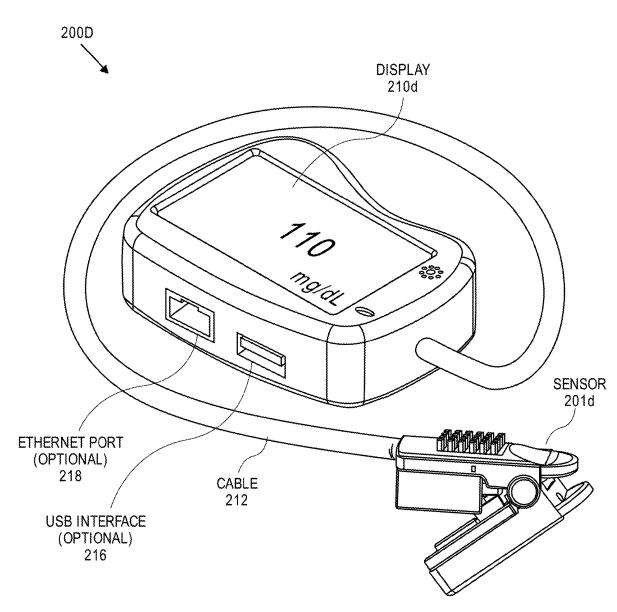
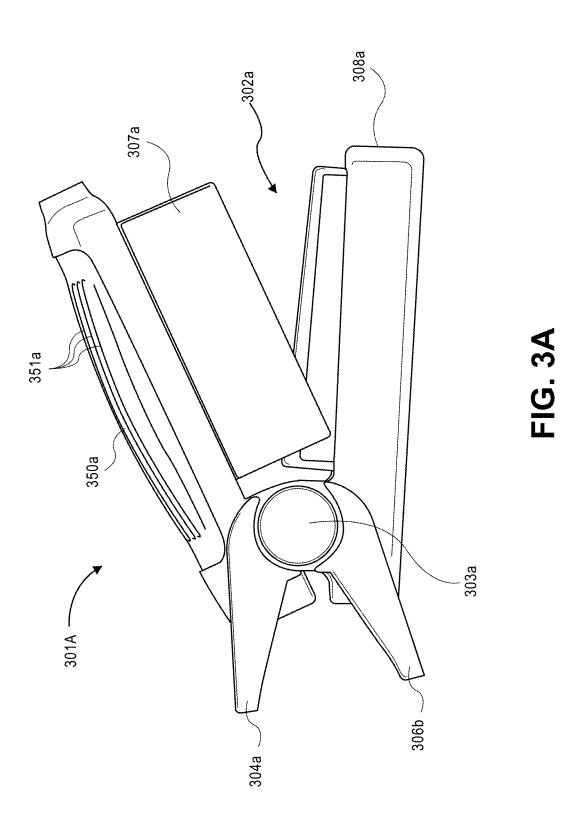
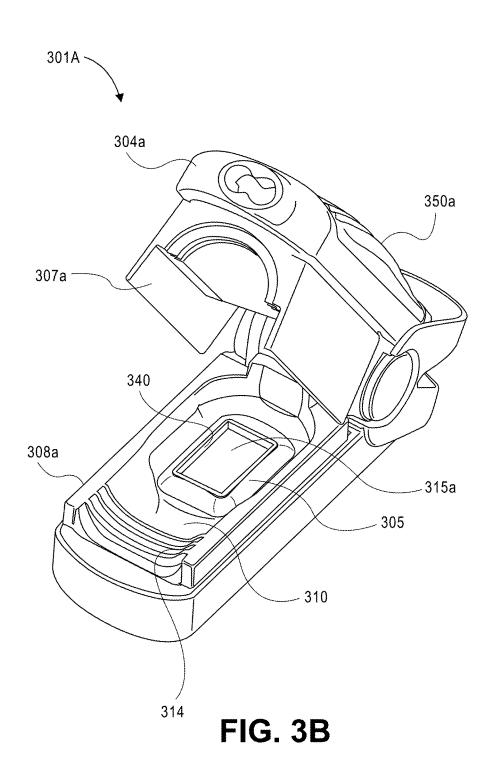


FIG. 2D

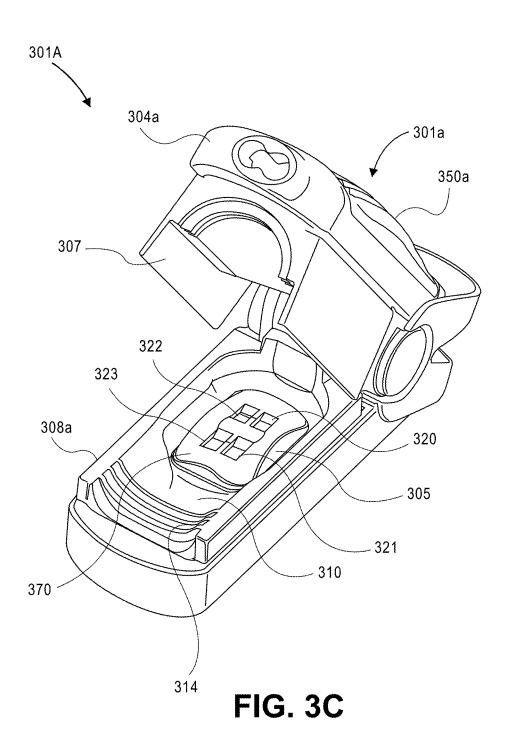
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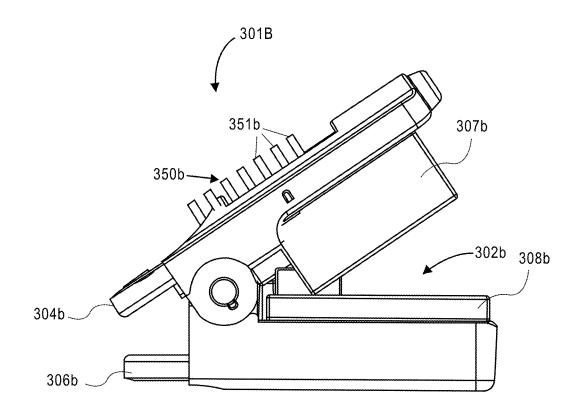


FIG. 3D

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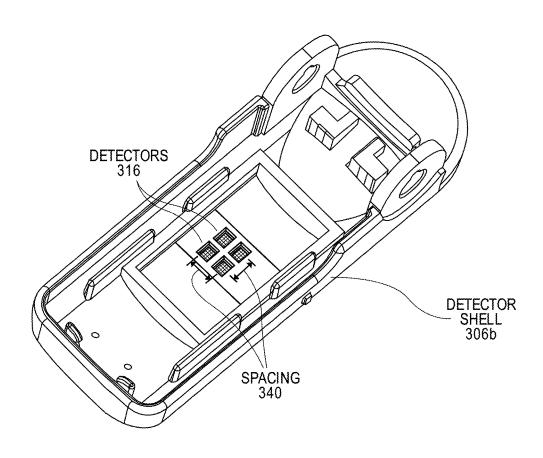
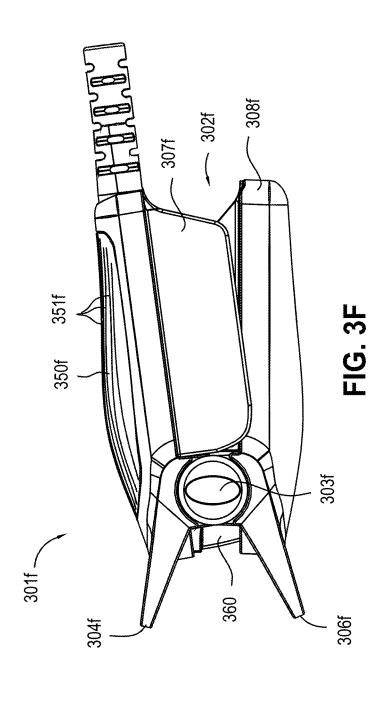


FIG. 3E

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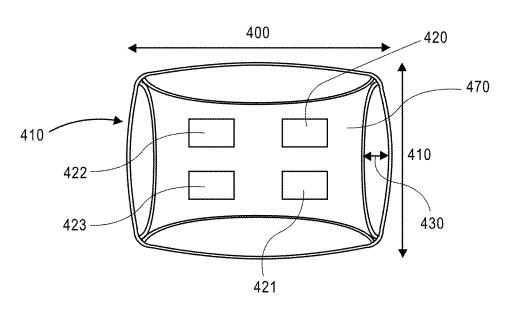


FIG. 4A

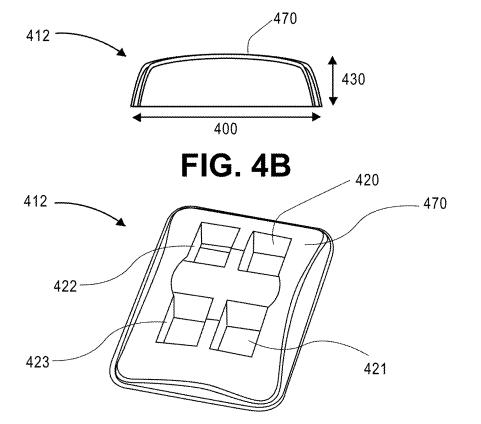
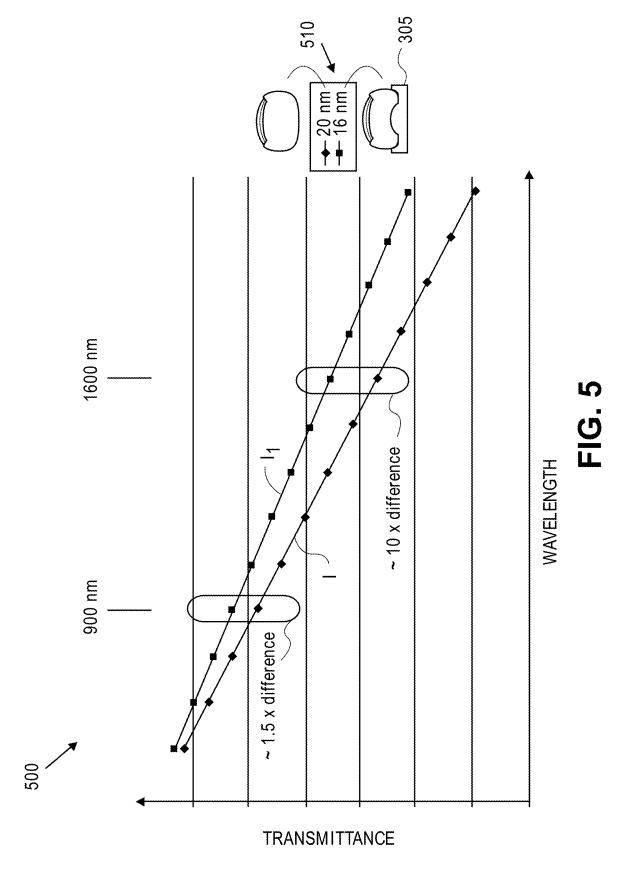


FIG. 4C

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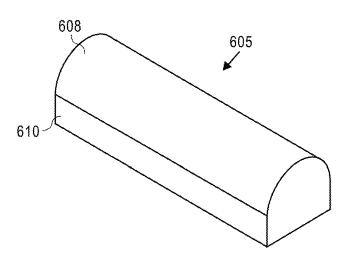


FIG. 6A

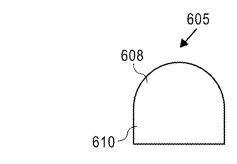


FIG. 6B

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FIG. 6C

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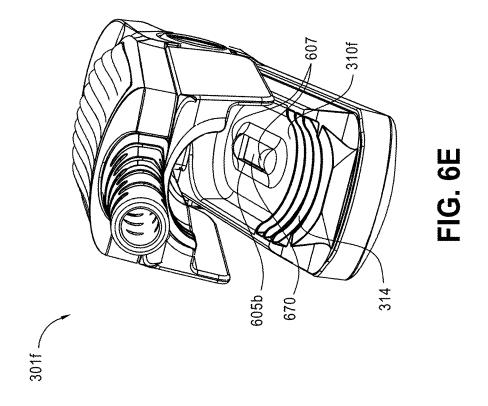
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FIG. 6D

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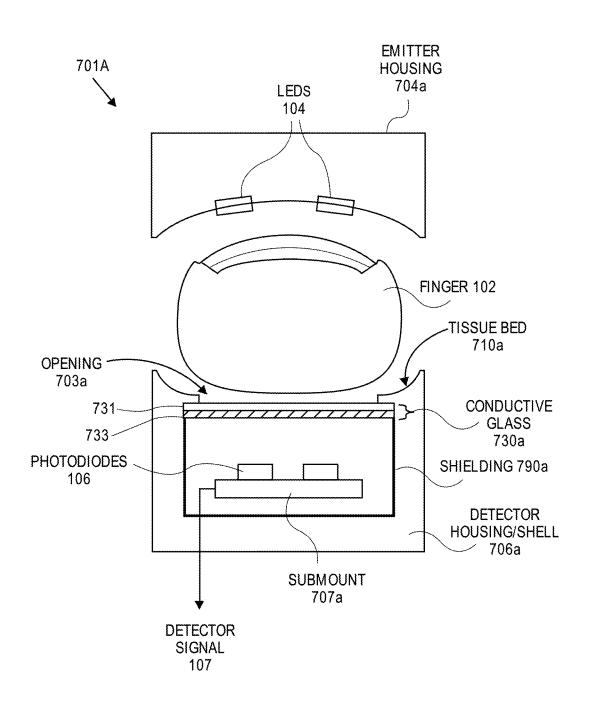


FIG. 7A

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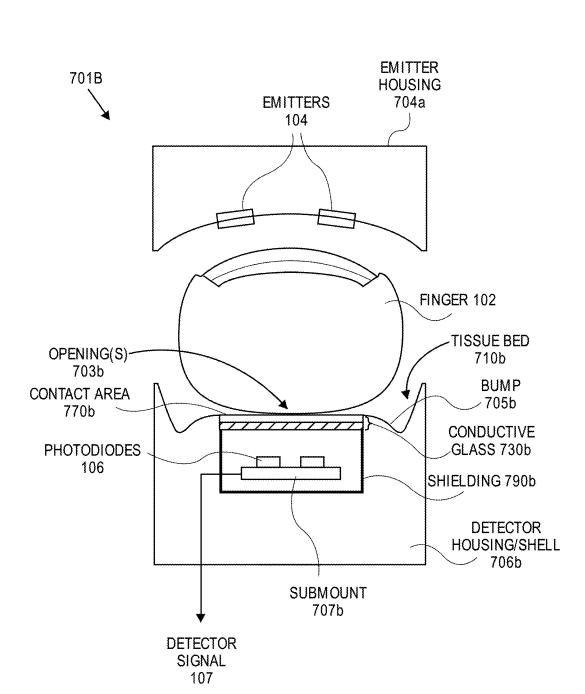
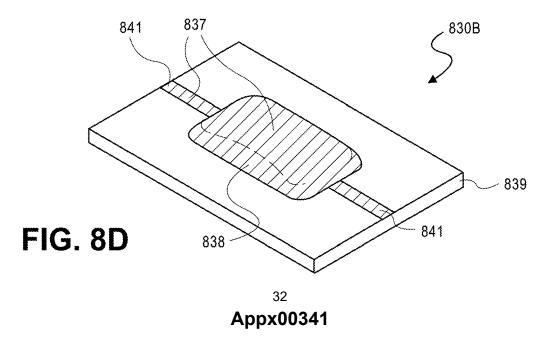


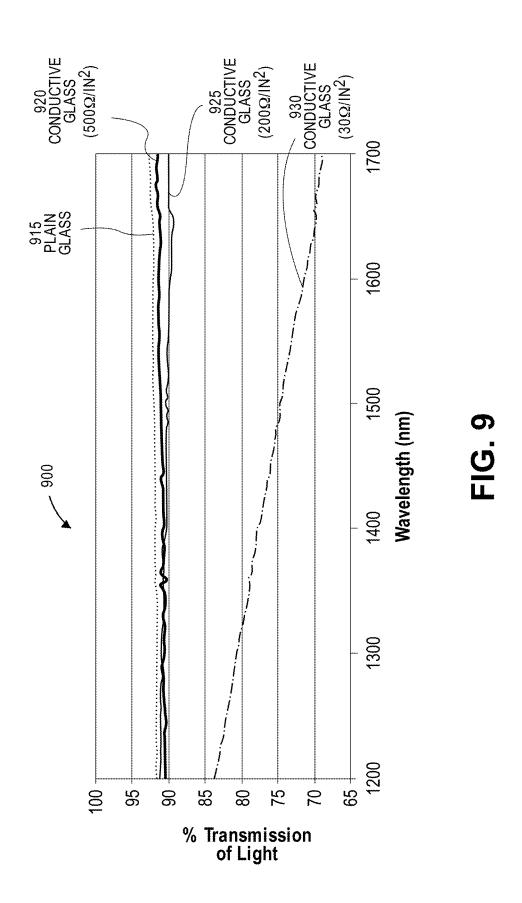
FIG. 7B

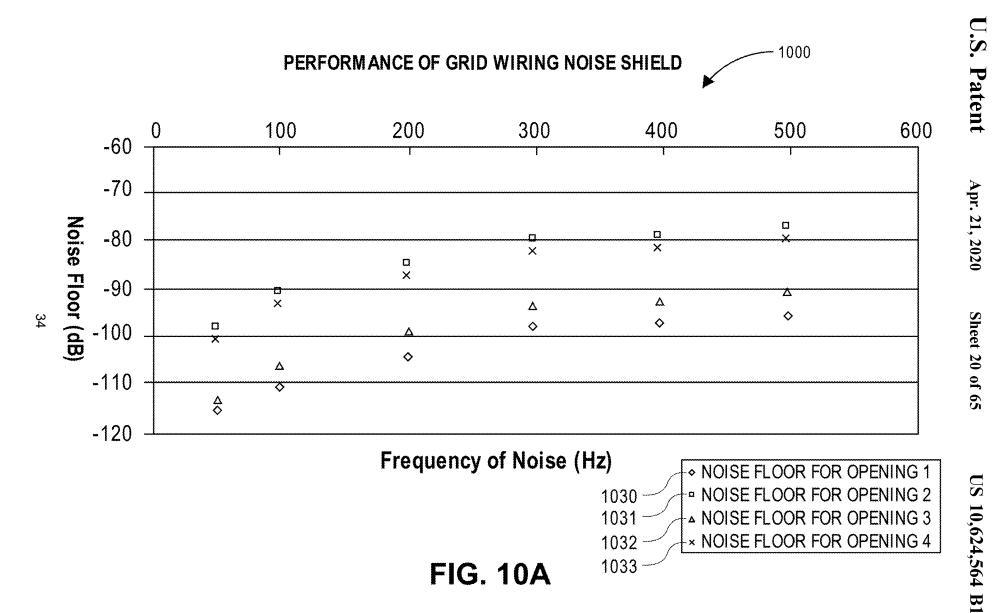
U.S. Patent Apr. 21, 2020 US 10,624,564 B1 **Sheet 18 of 65** 730 731 733 820 FIG. 8A 731 733 FIG. 8B 830A 733 - 835

FIG. 8C

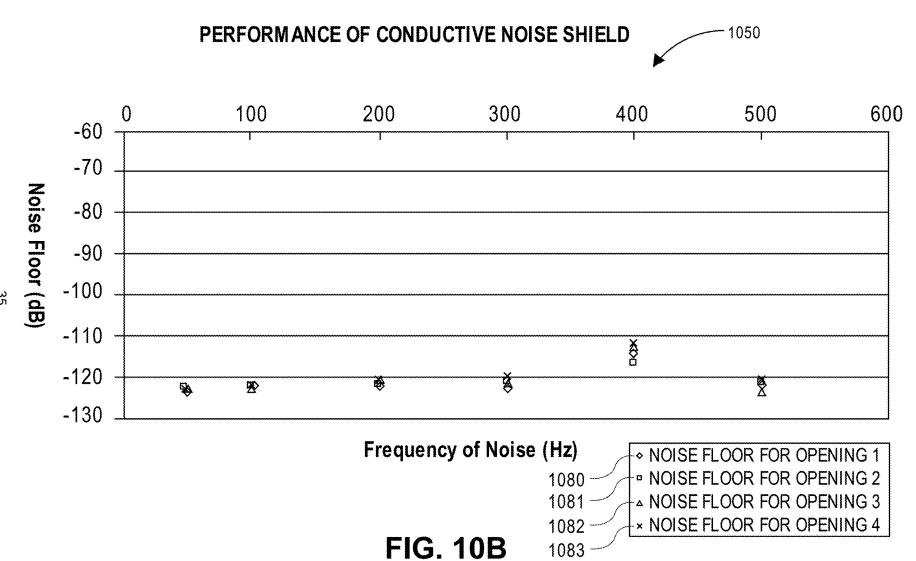


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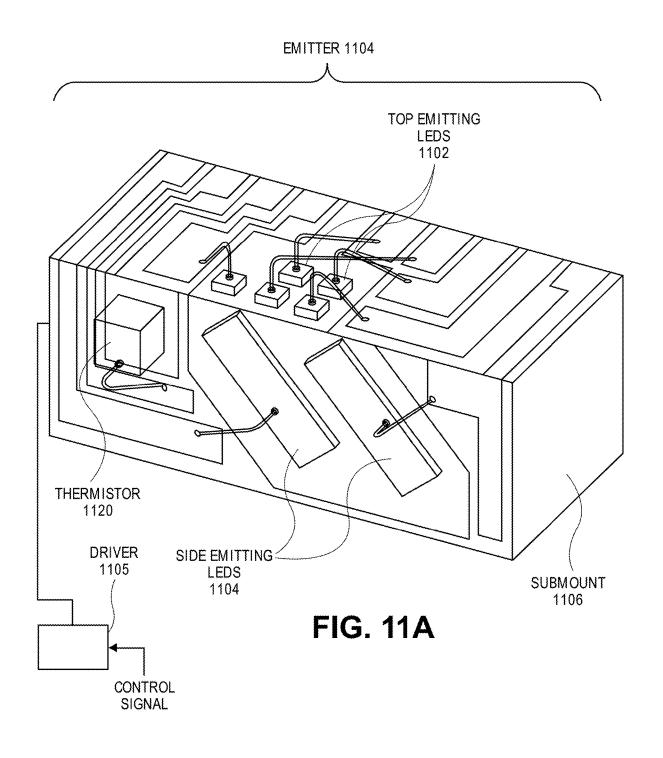




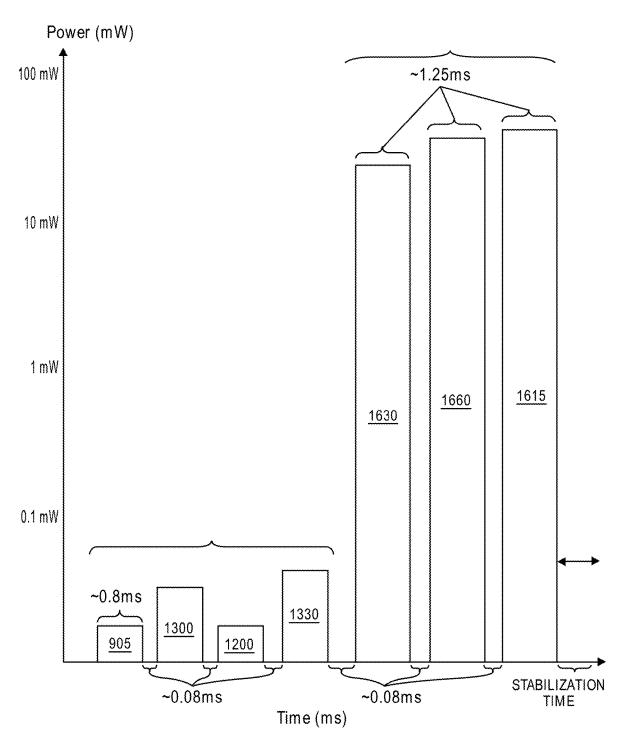
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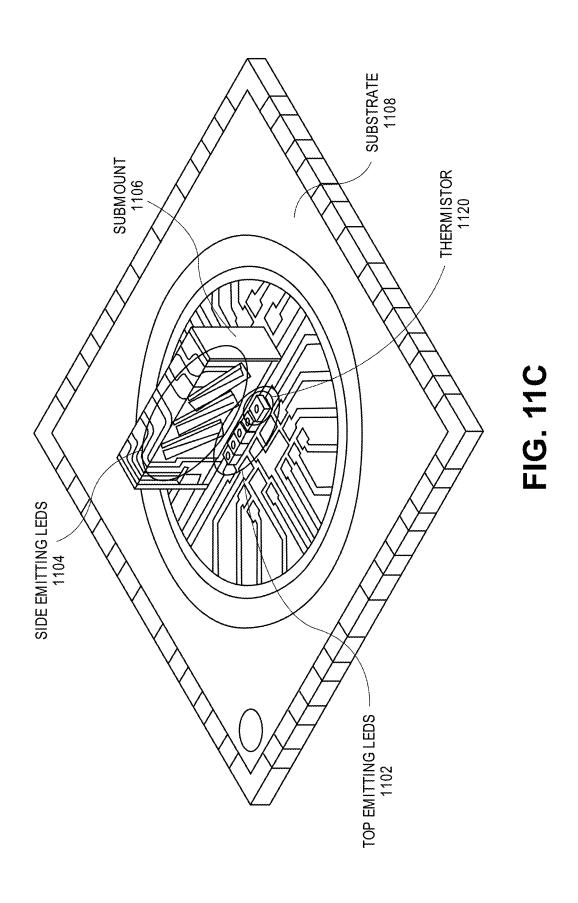


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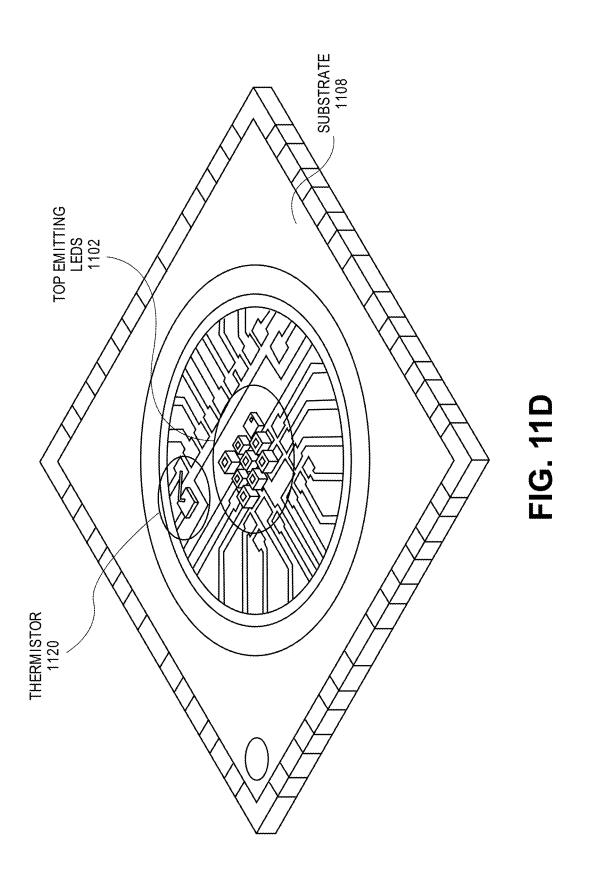


**FIG. 11B** 

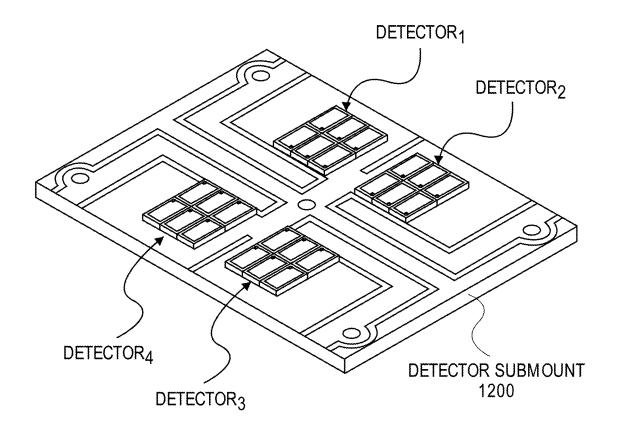
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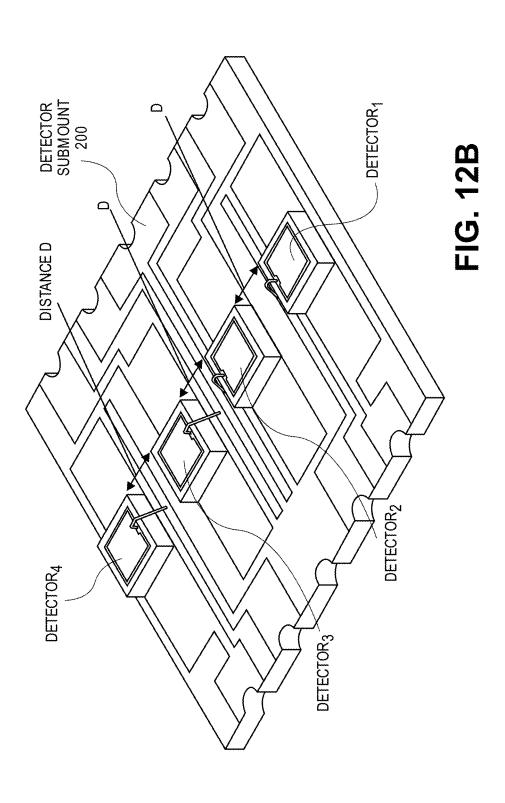


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**FIG. 12A** 

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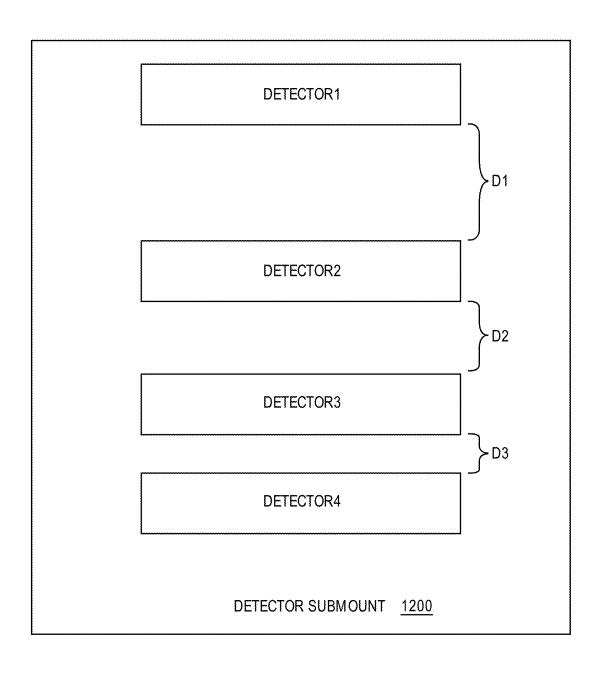
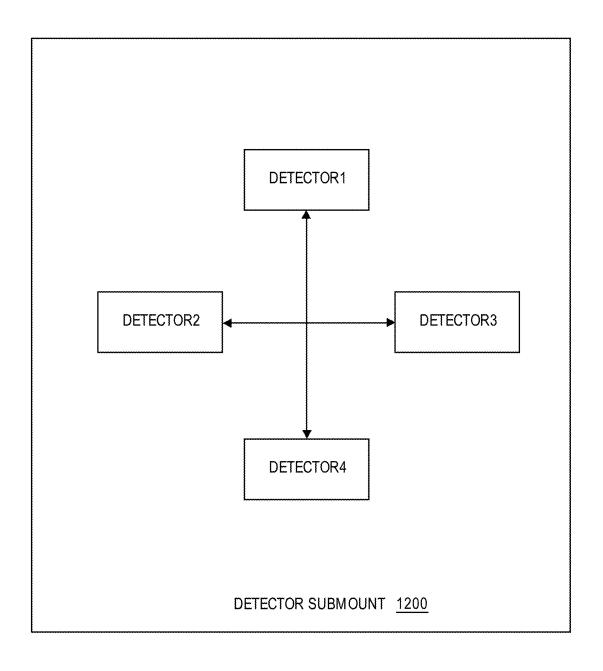


FIG. 12C

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**FIG. 12D** 

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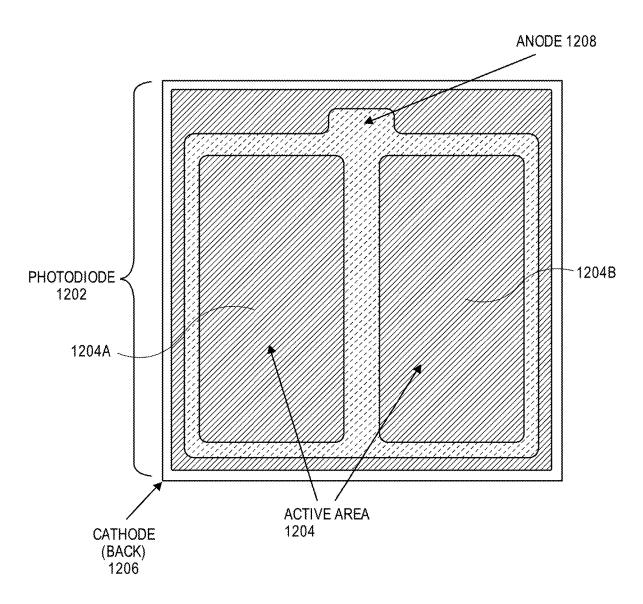


FIG. 12E

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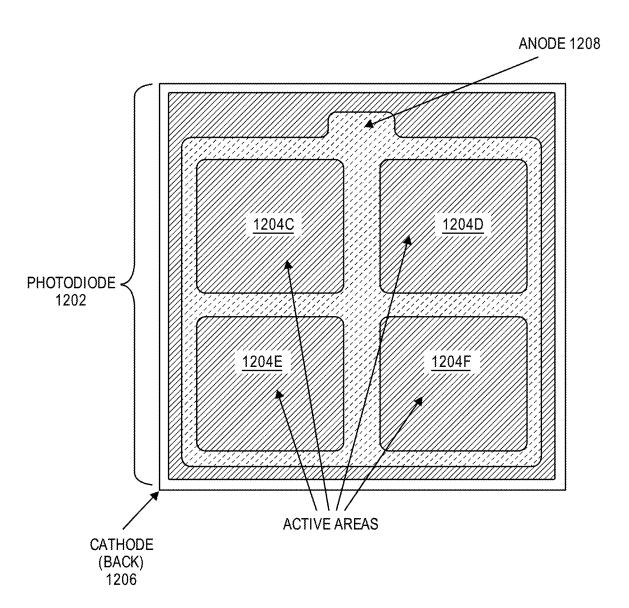


FIG. 12F

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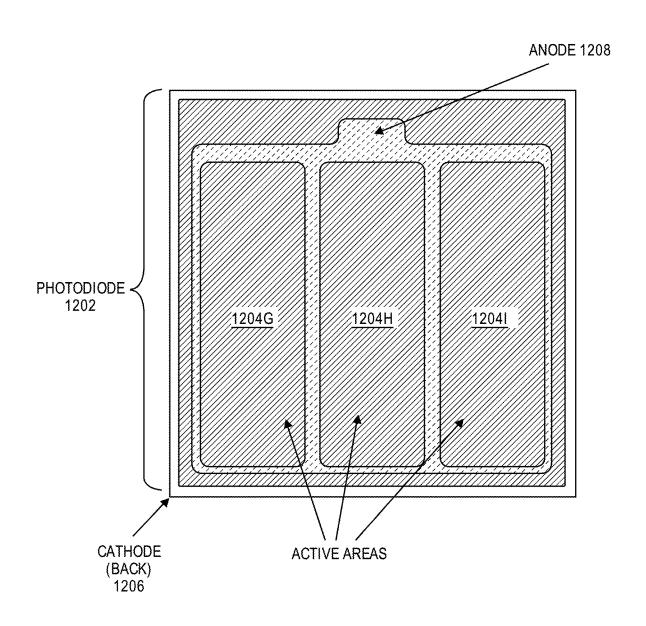


FIG. 12G

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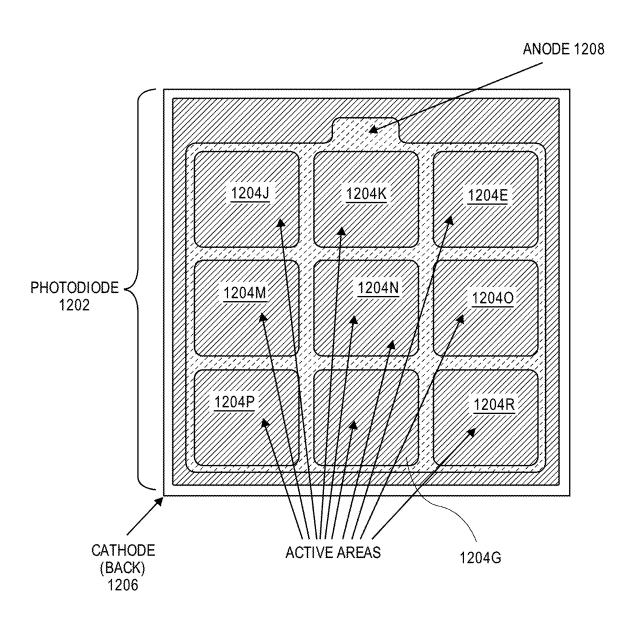
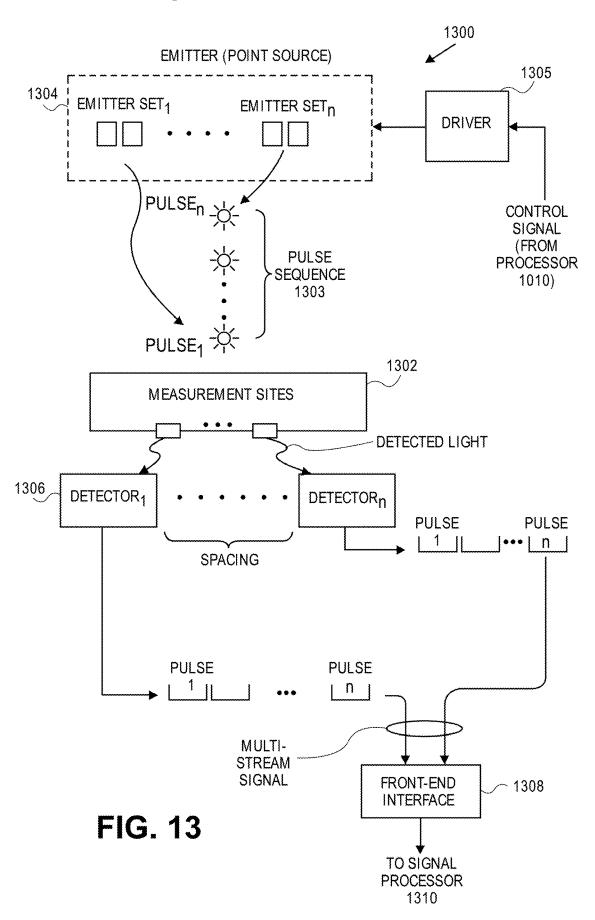
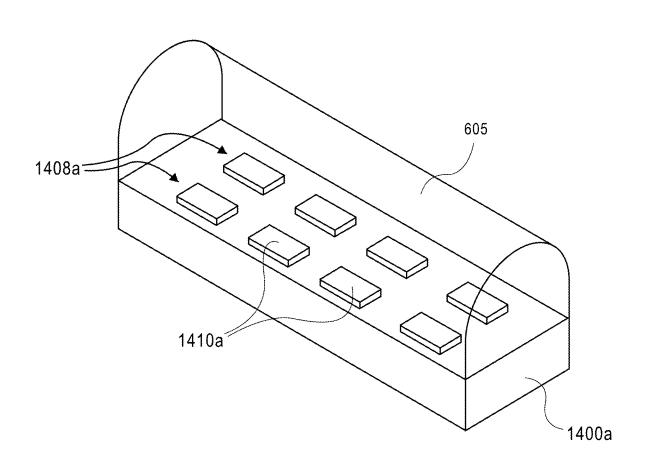


FIG. 12H

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**FIG. 14A** 

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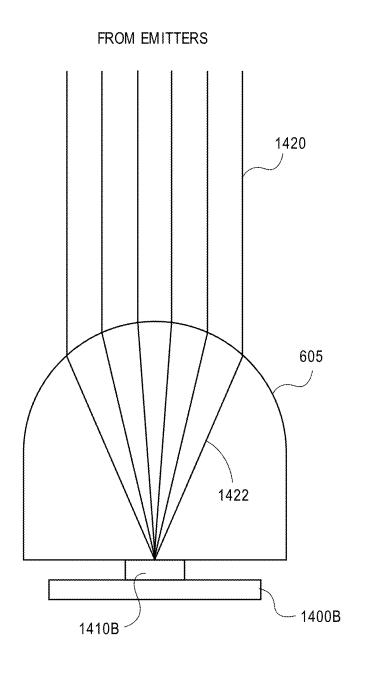


FIG. 14B

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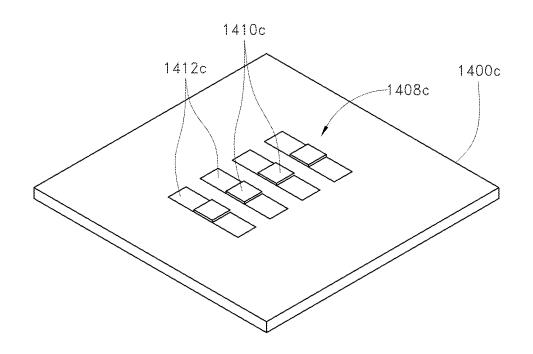
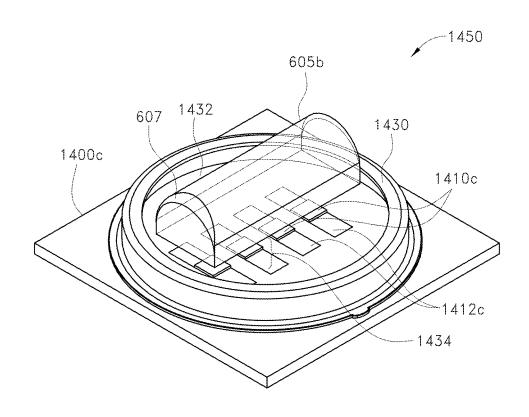


FIG. 14C

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**FIG. 14D** 

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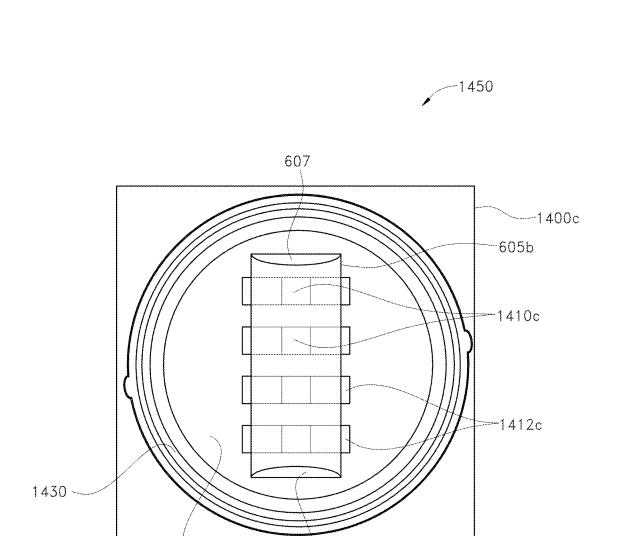


FIG. 14E

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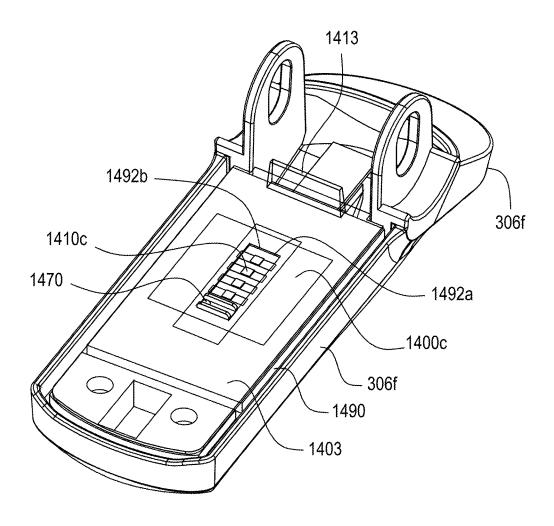


FIG. 14F

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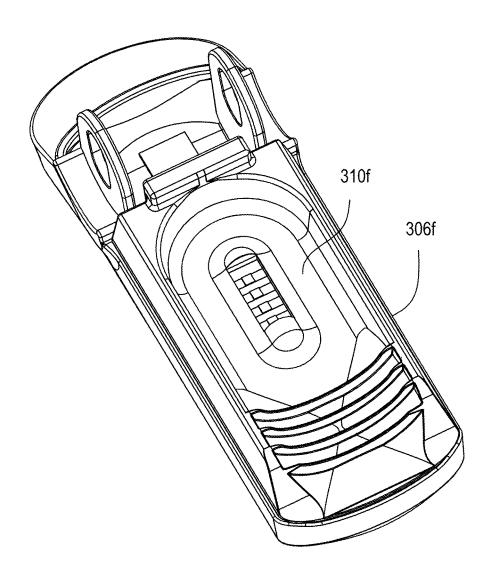


FIG. 14G

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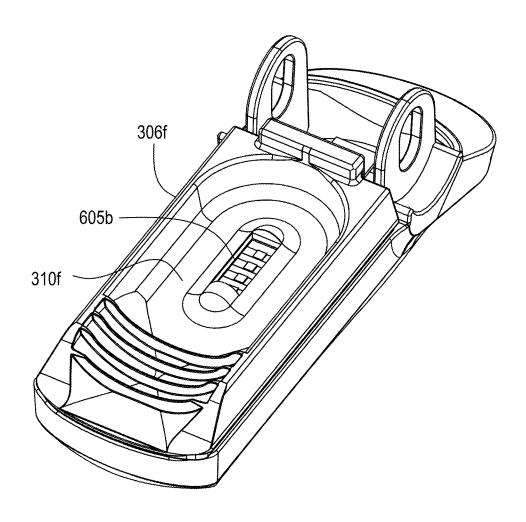


FIG. 14H

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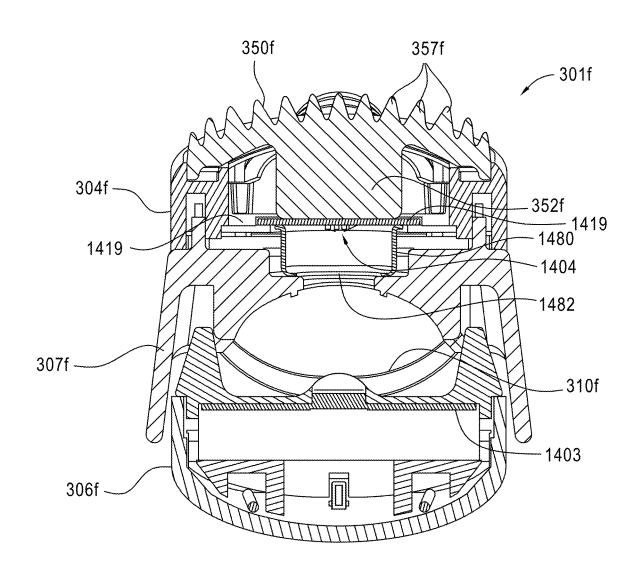
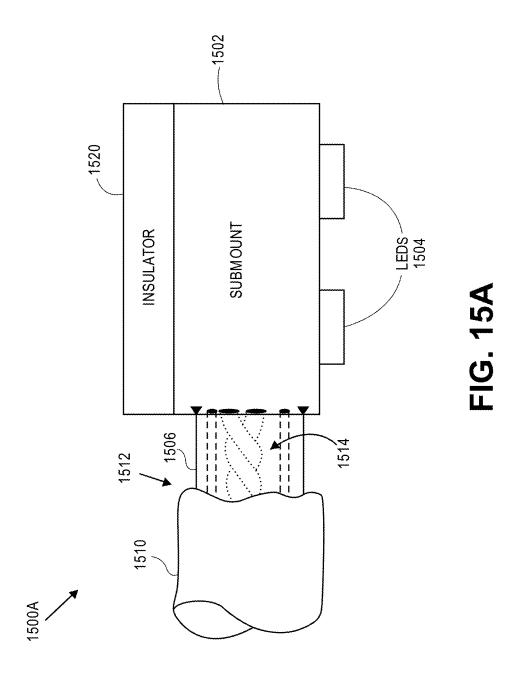
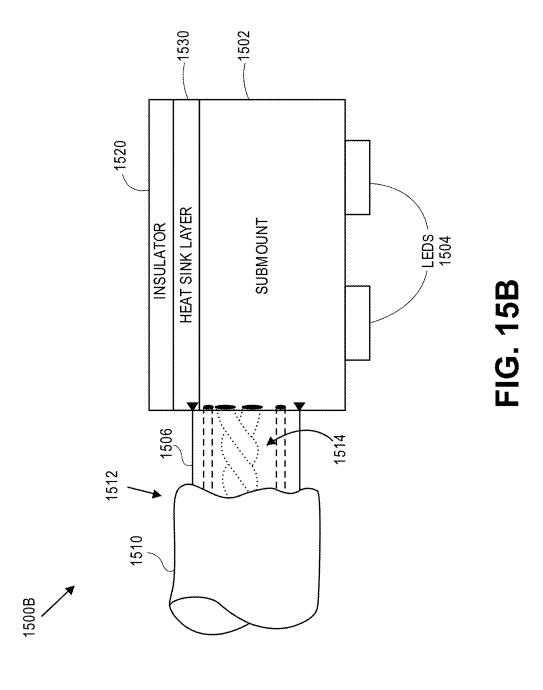


FIG. 141

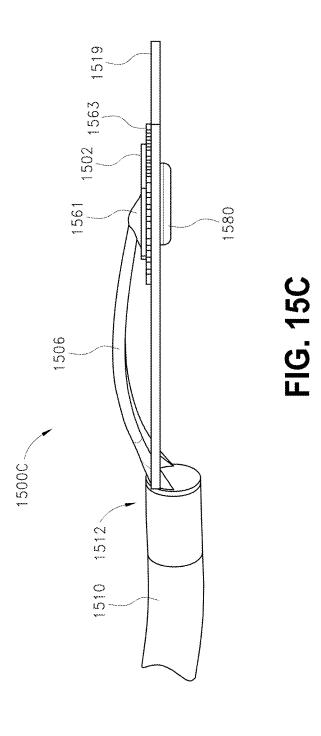
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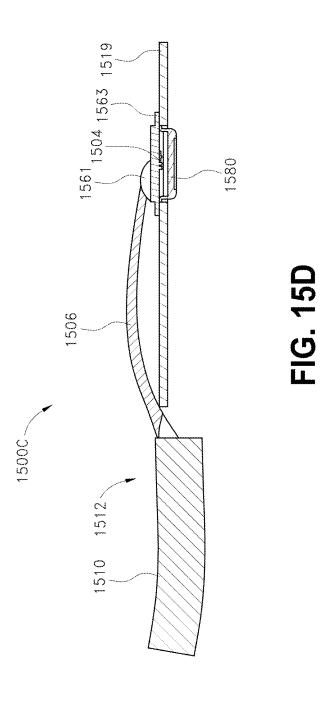
U.S. Patent Apr. 21, 2020 Sheet 45 of 65 US 10,624,564 B1



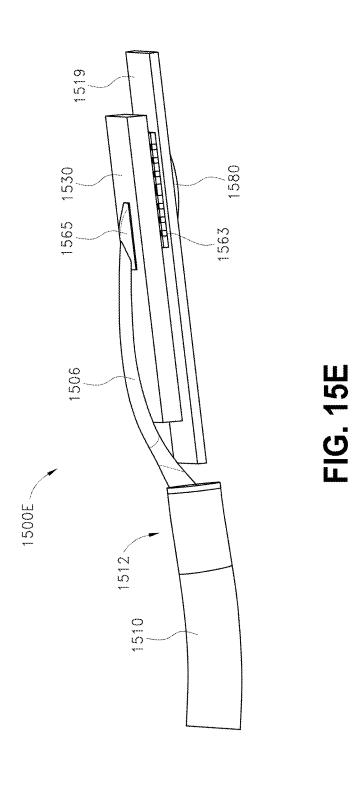
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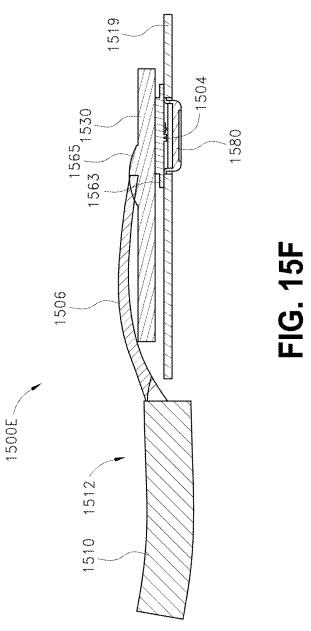


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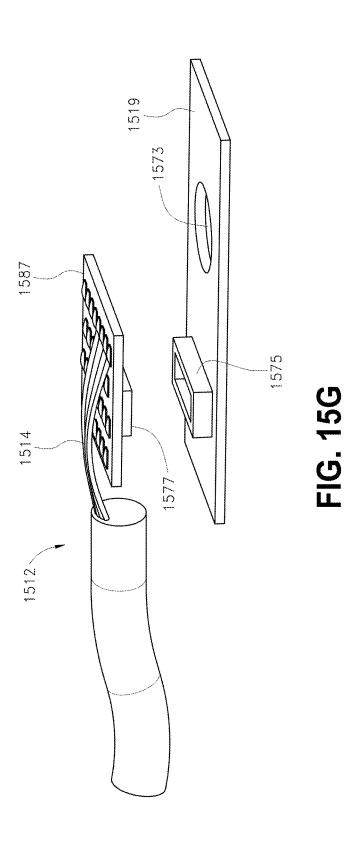


Case: 22-1972 Document: 33-2 Page: 70 Filed: 05/11/2023

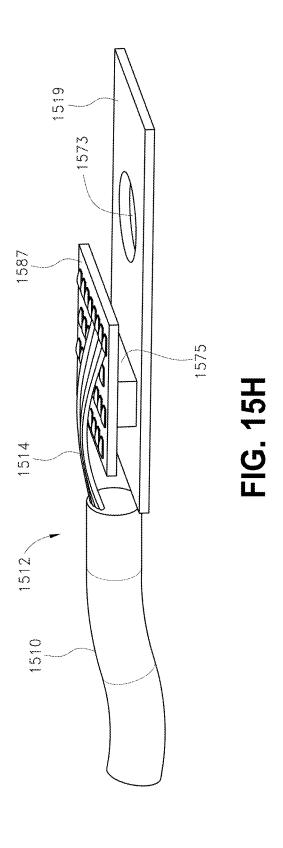
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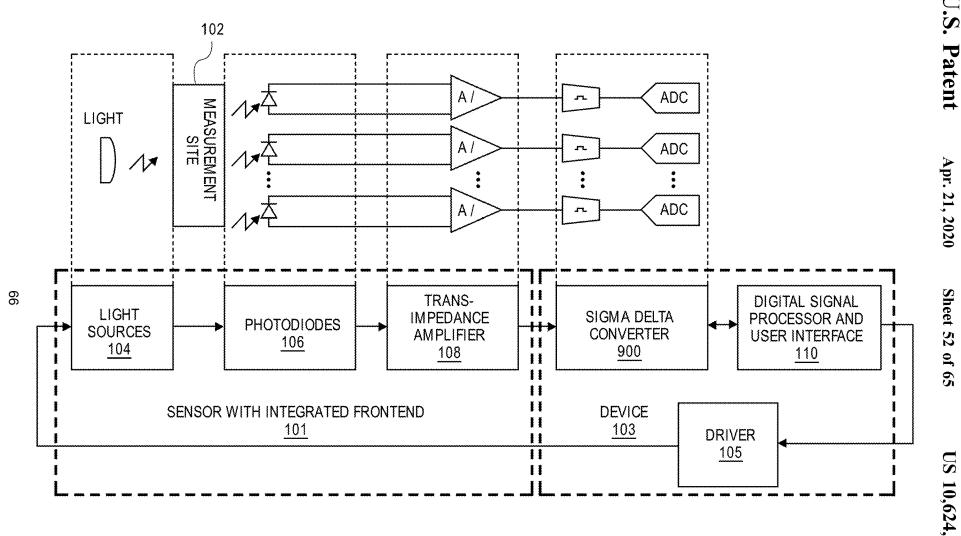
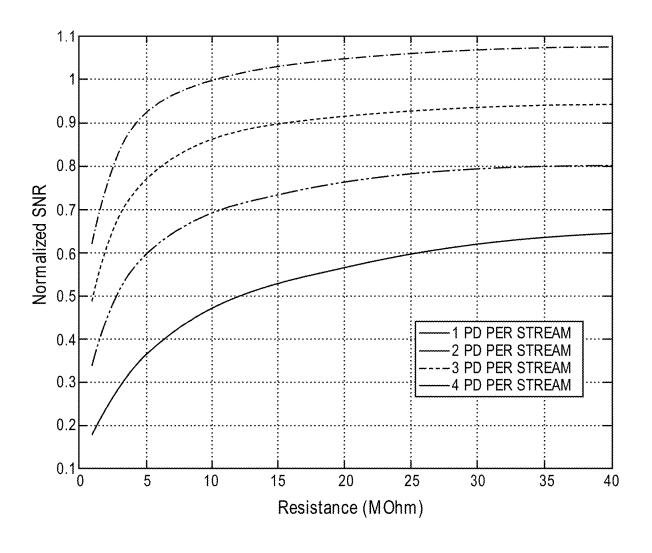


FIG. 151

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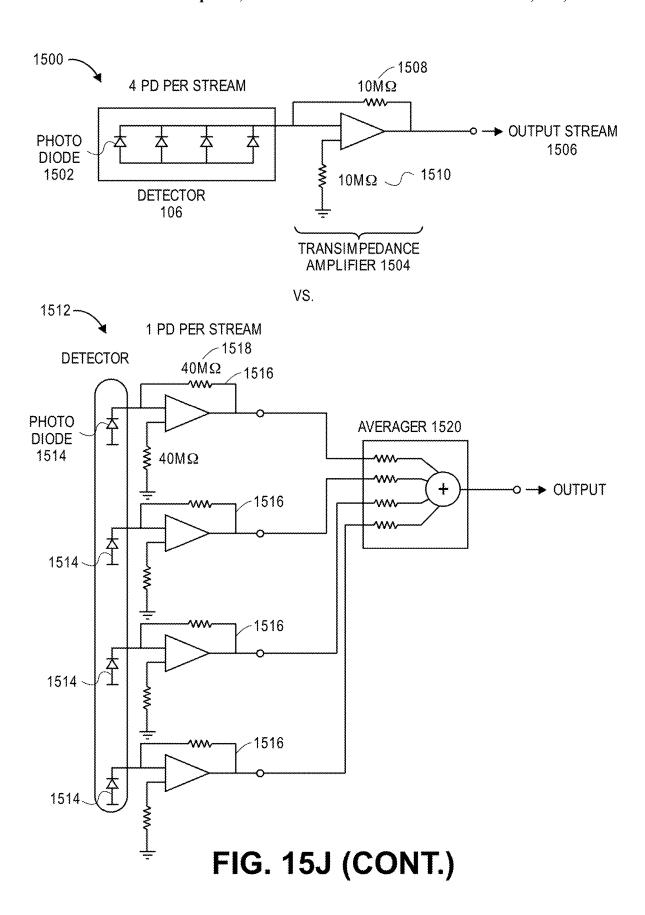
**FIG. 15J** 

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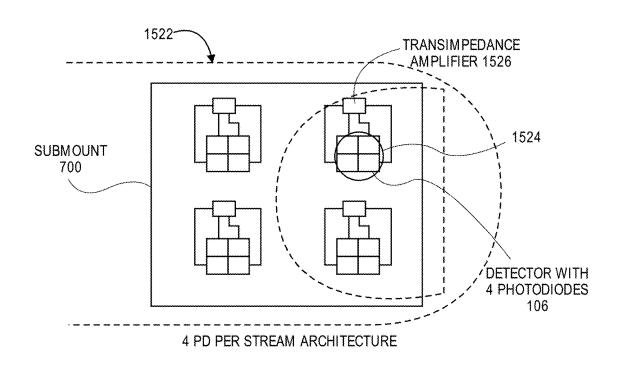


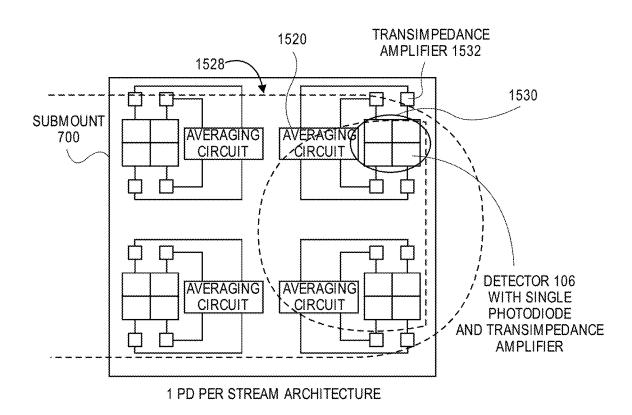
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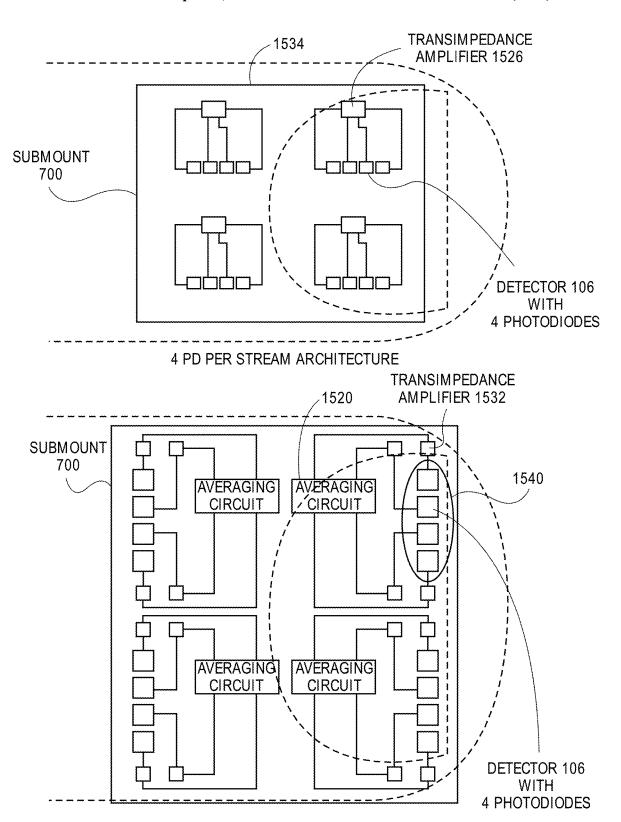
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**FIG. 15K** 

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1 PD PER STREAM ARCHITECTURE

**FIG. 15K (CONT.)** 

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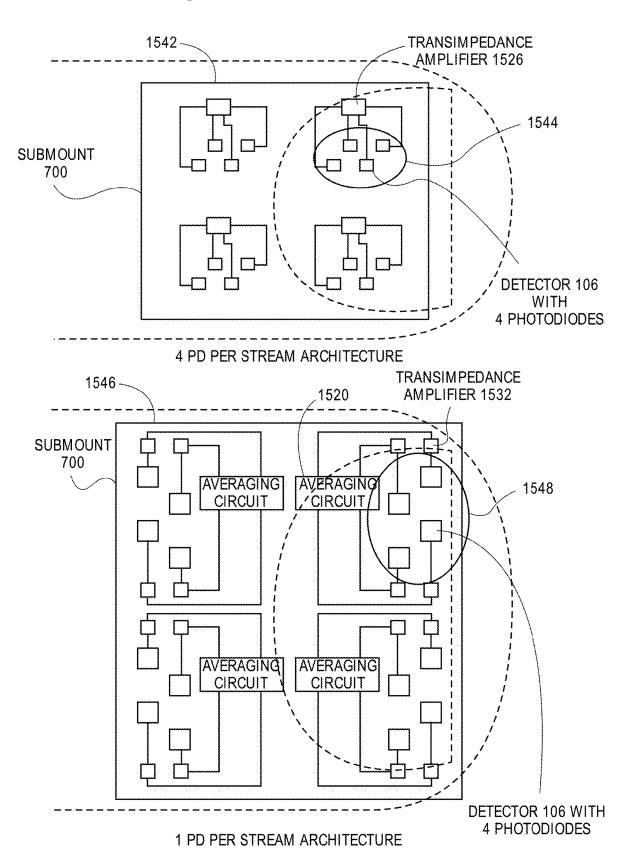


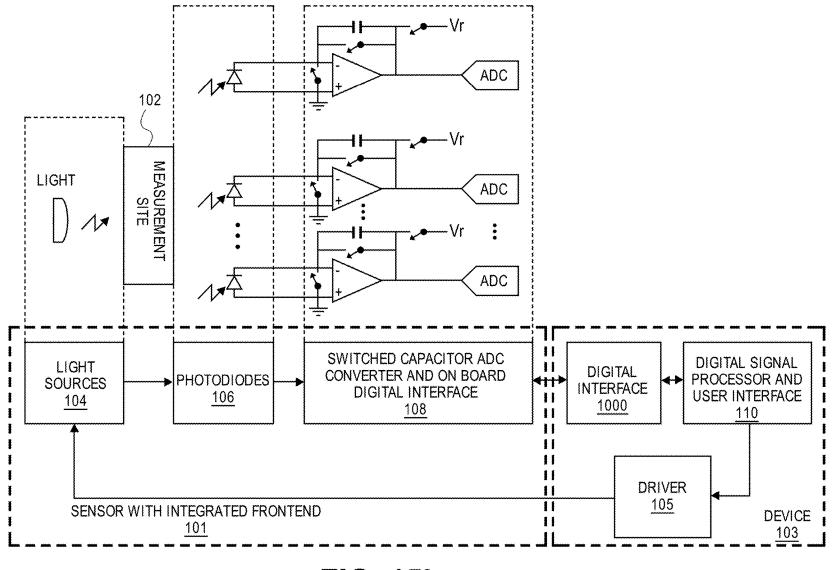
FIG. 15K (CONT.)

**Patent** 

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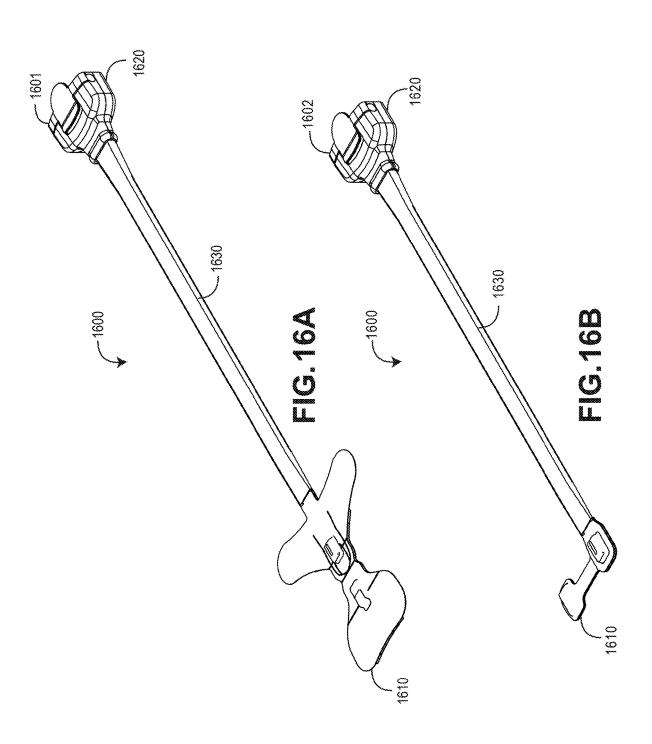
US 10,624,564 B1



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FIG. 15L

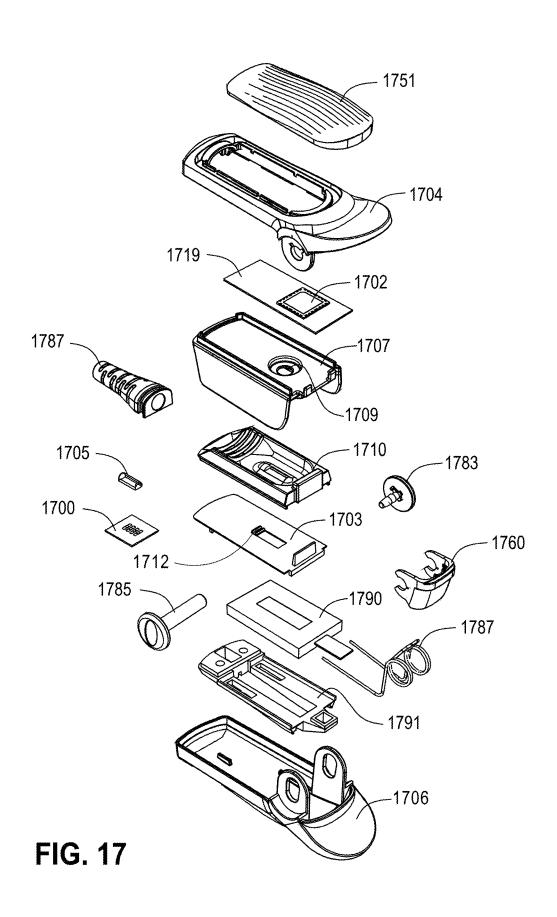
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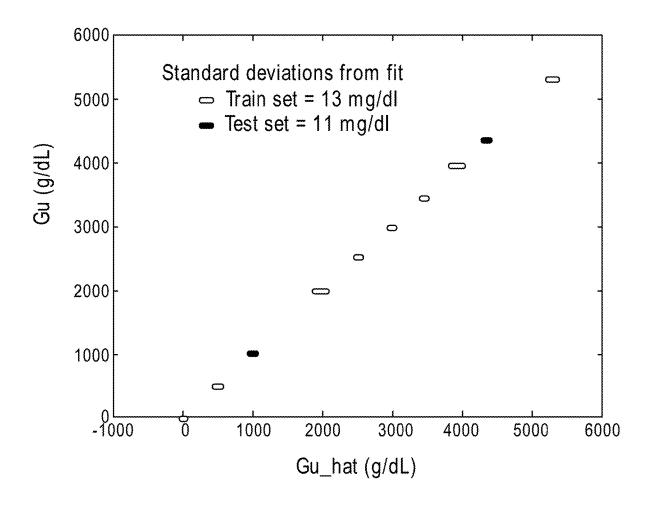


FIG. 18

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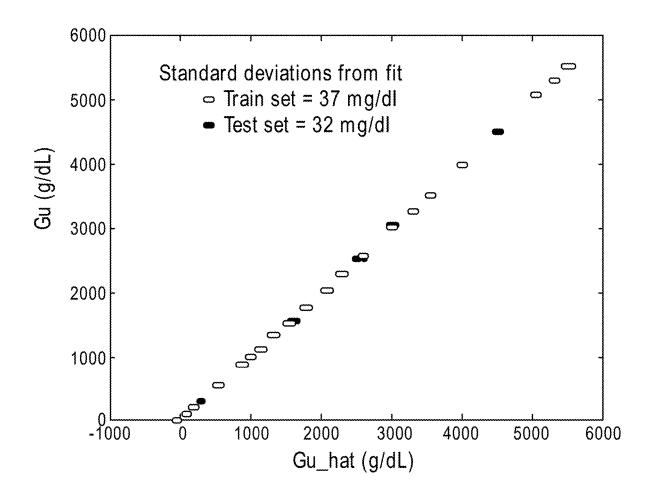


FIG. 19

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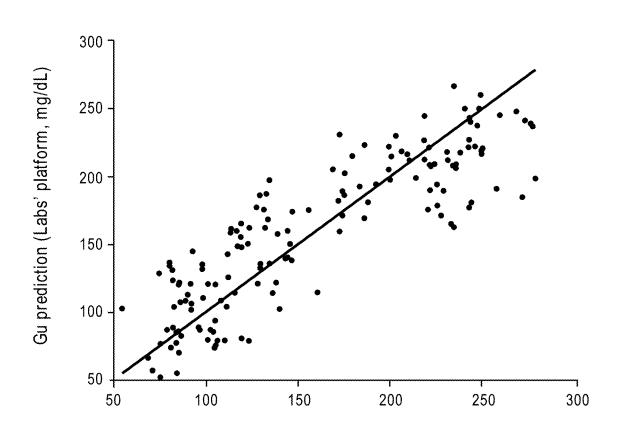


FIG. 20

Gu reference (YSI, mg/dL)

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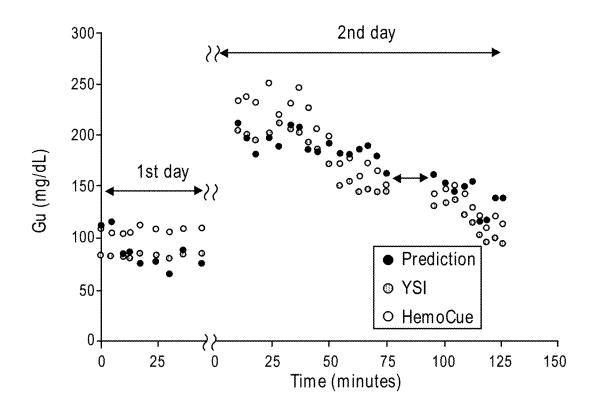


FIG. 21

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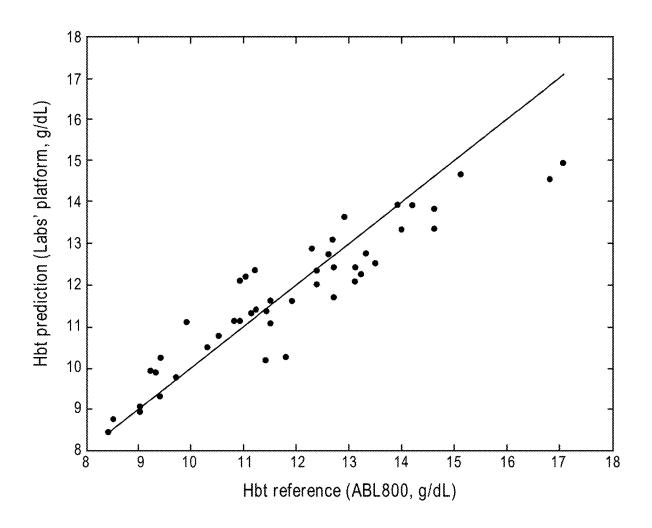


FIG. 22

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#### MULTI-STREAM DATA COLLECTION SYSTEM FOR NONINVASIVE MEASUREMENT OF BLOOD CONSTITUENTS

#### RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/534,949, filed Aug. 7, 2019, which is a continuation of U.S. patent application Ser. No. 16/409,515, filed May 10, 2019, which is a continuation of U.S. patent application Ser. No. 16/261,326, filed Jan. 29, 2019, which is a continuation of U.S. patent application Ser. No. 16/212, 537, filed Dec. 6, 2018, which is a continuation of U.S.  $_{\rm 15}$ patent application Ser. No. 14/981,290 filed Dec. 28, 2015, which is a continuation of U.S. patent application Ser. No. 12/829,352 filed Jul. 1, 2010, which is a continuation of U.S. patent application Ser. No. 12/534,827 filed Aug. 3, 2009, which claims the benefit of priority under 35 U.S.C. § 119(e) 20 of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/829,352 is also a continuation-in- 25 part of U.S. patent application Ser. No. 12/497,528 filed Jul. 2, 2009, which claims the benefit of priority under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, 61/078,228 filed Jul. 3, 2008, 61/078,207 filed Jul. 3, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/497,528 also claims the benefit of priority under 35 U.S.C. § 120 as a continuationin-part of the following U.S. Design patent application Ser. No. 29/323,409 filed Aug. 25, 2008 and Ser. No. 29/323,408 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/829, 352 is also a continuation-in-part of U.S. patent application Ser. No. 12/497,523 filed Jul. 2, 2009, which claims the 40 benefit of priority under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, 61/078, 228 filed Jul. 3, 2008, 61/078,207 filed Jul. 3, 2008, and 45 61/091,732 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/497,523 also claims the benefit of priority under 35 U.S.C. § 120 as a continuation-in-part of the following U.S. Design patent application Ser. No. 29/323,409 filed Aug. 25, 2008 and Ser. No. 29/323,408 filed Aug. 25, 2008.

This application is related to the following U.S. Patent Applications:

application Filing Ser. No. Date	Title	Attonery Docket
12/497,528 Jul. 2, 2009	Noise Shielding for Noninvasive Device	MASCER.006A
12/497,523 Jul. 2, 2009	Contoured Protrusion for Improving Spectroscopic Measurement of Blood Constituents	MASCER.007A
12/497,506 Jul. 2, 2009	Heat Sink for Noninvasive Medical Sensor	MASCER.011A
12/534,812 Aug. 3, 2009	Multi-Stream Sensor Front Ends for Non-Invasive Measurement of Blood Constituents	MASCER.003A

# 2 -continued

application Filing		
Ser. No. Date	Title	Attonery Docket
12/534,823 Aug. 3, 2009	Multi-Stream Sensor for Non-Invasive Measurement of Blood Constituents	MASCER.004A
12/534,825 Aug. 3, 2009	Multi-Stream Emitter for Non-Invasive Measurement of Blood Constituents	MASCER.005A

The foregoing applications are hereby incorporated by reference in their entirety.

#### BACKGROUND

The standard of care in caregiver environments includes patient monitoring through spectroscopic analysis using, for example, a pulse oximeter. Devices capable of spectroscopic analysis generally include a light source(s) transmitting optical radiation into or reflecting off a measurement site, such as, body tissue carrying pulsing blood. After attenuation by tissue and fluids of the measurement site, a photodetection device(s) detects the attenuated light and outputs a detector signal(s) responsive to the detected attenuated light. A signal processing device(s) process the detector(s) signal(s) and outputs a measurement indicative of a blood constituent of interest, such as glucose, oxygen, met hemoglobin, total hemoglobin, other physiological parameters, or other data or combinations of data useful in determining a state or trend of wellness of a patient.

In noninvasive devices and methods, a sensor is often adapted to position a finger proximate the light source and light detector. For example, noninvasive sensors often include a clothespin-shaped housing that includes a contoured bed conforming generally to the shape of a finger.

#### **SUMMARY**

This disclosure describes embodiments of noninvasive methods, devices, and systems for measuring a blood constituent or analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. These characteristics can relate, for example, to pulse rate, hydration, trending information and analysis, and the like.

In an embodiment, the system includes a noninvasive sensor and a patient monitor communicating with the non-invasive sensor. The non-invasive sensor may include different architectures to implement some or all of the disclosed features. In addition, an artisan will recognize that the non-invasive sensor may include or may be coupled to other components, such as a network interface, and the like. Moreover, the patient monitor may include a display device, a network interface communicating with any one or combination of a computer network, a handheld computing device, a mobile phone, the Internet, or the like. In addition, embodiments may include multiple optical sources that emit light at a plurality of wavelengths and that are arranged from the perspective of the light detector(s) as a point source.

In an embodiment, a noninvasive device is capable of producing a signal responsive to light attenuated by tissue at a measurement site. The device may comprise an optical source and a plurality of photodetectors. The optical source is configured to emit optical radiation at least at wavelengths between about 1600 nm and about 1700 nm. The photodetectors are configured to detect the optical radiation from

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said optical source after attenuation by the tissue of the measurement site and each output a respective signal stream responsive to the detected optical radiation.

In an embodiment, a noninvasive, physiological sensor is capable of outputting a signal responsive to a blood analyte 5 present in a monitored patient. The sensor may comprise a sensor housing, an optical source, and photodetectors. The optical source is positioned by the housing with respect to a tissue site of a patient when said housing is applied to the patient. The photodetectors are positioned by the housing 10 with respect to said tissue site when the housing is applied to the patient with a variation in path length among at least some of the photodetectors from the optical source. The photodetectors are configured to detect a sequence of optical radiation from the optical source after attenuation by tissue 15 of the tissue site. The photodetectors may be each configured to output a respective signal stream responsive to the detected sequence of optical radiation. An output signal responsive to one or more of the signal streams is then usable to determine the blood analyte based at least in part 20 on the variation in path length.

In an embodiment, a method of measuring an analyte based on multiple streams of optical radiation measured from a measurement site is provided. A sequence of optical radiation pulses is emitted to the measurement site. At a first 25 location, a first stream of optical radiation is detected from the measurement site. At least at one additional location different from the first location, an additional stream of optical radiation is detected from the measurement site. An output measurement value indicative of the analyte is then 30 determined based on the detected streams of optical radia-

In various embodiments, the present disclosure relates to an interface for a noninvasive sensor that comprises a front-end adapted to receive an input signals from optical 35 detectors and provide corresponding output signals. In an embodiment, the front-end is comprised of switched-capacitor circuits that are capable of handling multiple streams of signals from the optical detectors. In another embodiment, the front-end comprises transimpedance amplifiers that are 40 capable of handling multiple streams of input signals. In addition, the transimpedance amplifiers may be configured based on the characteristics of the transimpedance amplifier itself, the characteristics of the photodiodes, and the number of photodiodes coupled to the transimpedance amplifier.

In disclosed embodiments, the front-ends are employed in noninvasive sensors to assist in measuring and detecting various analytes. The disclosed noninvasive sensor may also include, among other things, emitters and detectors positioned to produce multi-stream sensor information. An arti- 50 san will recognize that the noninvasive sensor may have different architectures and may include or be coupled to other components, such as a display device, a network interface, and the like. An artisan will also recognize that the front-ends may be employed in any type of noninvasive 55

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to receive signals from a plurality of detectors in the sensor; a set of transimpedance amplifiers configured to convert the 60 signals from the plurality of detectors into an output signal having a stream for each of the plurality of detectors; and an output configured to provide the output signal.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to 65 receive signals from a plurality of detectors in the sensor; a set of switched capacitor circuits configured to convert the

signals from the plurality of detectors into a digital output signal having a stream for each of the plurality of detectors; and an output configured to provide the digital output signal.

In an embodiment, a conversion processor for a physiological, noninvasive sensor comprises: a multi-stream input configured to receive signals from a plurality of detectors in the sensor, wherein the signals are responsive to optical radiation from a tissue site; a modulator that converts the multi-stream input into a digital bit-stream; and a signal processor that produces an output signal from the digital

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to receive signals from a plurality of detectors in the sensor; a set of respective transimpedance amplifiers for each detector configured to convert the signals from the plurality of detectors into an output signal having a stream for each of the plurality of detectors; and an output configured to provide the output signal.

In certain embodiments, a noninvasive sensor interfaces with tissue at a measurement site and deforms the tissue in a way that increases signal gain in certain desired wavelengths.

In some embodiments, a detector for the sensor may comprise a set of photodiodes that are arranged in a spatial configuration. This spatial configuration may allow, for example, signal analysis for measuring analytes like glucose. In various embodiments, the detectors can be arranged across multiple locations in a spatial configuration. The spatial configuration provides a geometry having a diversity of path lengths among the detectors. For example, the detector in the sensor may comprise multiple detectors that are arranged to have a sufficient difference in mean path length to allow for noise cancellation and noise reduction.

In an embodiment, a physiological, noninvasive detector is configured to detect optical radiation from a tissue site. The detector comprises a set of photodetectors and a conversion processor. The set of photodetectors each provide a signal stream indicating optical radiation from the tissue site. The set of photodetectors are arranged in a spatial configuration that provides a variation in path lengths between at least some of the photodetectors. The conversion processor that provides information indicating an analyte in the tissue site based on ratios of pairs of the signal streams.

The present disclosure, according to various embodiments, relates to noninvasive methods, devices, and systems for measuring a blood analyte, such as glucose. In the present disclosure, blood analytes are measured noninvasively based on multi-stream infrared and near-infrared spectroscopy. In some embodiments, an emitter may include one or more sources that are configured as a point optical source. In addition, the emitter may be operated in a manner that allows for the measurement of an analyte like glucose. In embodiments, the emitter may comprise a plurality of LEDs that emit a sequence of pulses of optical radiation across a spectrum of wavelengths. In addition, in order to achieve the desired SNR for detecting analytes like glucose, the emitter may be driven using a progression from low power to higher power. The emitter may also have its duty cycle modified to achieve a desired SNR.

In an embodiment, a multi-stream emitter for a noninvasive, physiological device configured to transmit optical radiation in a tissue site comprises: a set of optical sources arranged as a point optical source; and a driver configured to drive the at least one light emitting diode and at least one optical source to transmit near-infrared optical radiation at

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sufficient power to measure an analyte in tissue that responds to near-infrared optical radiation.

In an embodiment, an emitter for a noninvasive, physiological device configured to transmit optical radiation in a tissue site comprises: a point optical source comprising an optical source configured to transmit infrared and nearinfrared optical radiation to a tissue site; and a driver configured to drive the point optical source at a sufficient power and noise tolerance to effectively provide attenuated optical radiation from a tissue site that indicates an amount of glucose in the tissue site.

In an embodiment, a method of transmitting a stream of pulses of optical radiation in a tissue site is provided. At least one pulse of infrared optical radiation having a first pulse width is transmitted at a first power. At least one pulse of near-infrared optical radiation is transmitted at a power that is higher than the first power.

In an embodiment, a method of transmitting a stream of pulses of optical radiation in a tissue site is provided. At least 20 one pulse of infrared optical radiation having a first pulse width is transmitted at a first power. At least one pulse of near-infrared optical radiation is then transmitted, at a second power that is higher than the first power.

For purposes of summarizing the disclosure, certain 25 aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the inventions disclosed herein. Thus, the inventions disclosed herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as can be taught or suggested herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Throughout the drawings, reference numbers can be rements. The drawings are provided to illustrate embodiments of the inventions described herein and not to limit the scope thereof.

FIG. 1 illustrates a block diagram of an example data collection system capable of noninvasively measuring one 45 or more blood analytes in a monitored patient, according to an embodiment of the disclosure:

FIGS. 2A-2D illustrate an exemplary handheld monitor and an exemplary noninvasive optical sensor of the patient monitoring system of FIG. 1, according to embodiments of 50 the disclosure;

FIGS. 3A-3C illustrate side and perspective views of an exemplary noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of

FIG. 3D illustrates a side view of another example noninvasive sensor housing including a heat sink, according to an embodiment of the disclosure;

FIG. 3E illustrates a perspective view of an example noninvasive sensor detector shell including example detec- 60 tors, according to an embodiment of the disclosure;

FIG. 3F illustrates a side view of an example noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

FIGS. 4A through 4C illustrate top elevation, side and top 65 perspective views of an example protrusion, according to an embodiment of the disclosure;

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FIG. 5 illustrates an example graph depicting possible effects of a protrusion on light transmittance, according to an embodiment of the disclosure;

FIGS. 6A through 6D illustrate perspective, front elevation, side and top views of another example protrusion, according to an embodiment of the disclosure;

FIG. 6E illustrates an example sensor incorporating the protrusion of FIGS. 6A through 6D, according to an embodiment of the disclosure;

FIGS. 7A through 7B illustrate example arrangements of conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

FIGS. 8A through 8D illustrate an example top elevation view, side views, and a bottom elevation view of the conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

FIG. 9 shows example comparative results obtained by an embodiment of a sensor;

FIGS. 10A and 10B illustrate comparative noise floors of various embodiments of the present disclosure;

FIG. 11A illustrates an exemplary emitter that may be employed in the sensor, according to an embodiment of the disclosure:

FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring blood constituents, according to an embodiment of the disclosure;

FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

FIG. 12A illustrates an example detector portion that may be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

FIGS. 12B through 12D illustrate exemplary arrangements of detectors that may be employed in an embodiment used to indicate correspondence between referenced ele- 40 of the sensor, according to some embodiments of the disclosure:

> FIGS. 12E through 12H illustrate exemplary structures of photodiodes that may be employed in embodiments of the detectors, according to some embodiments of the disclosure;

FIG. 13 illustrates an example multi-stream operation of the system of FIG. 1, according to an embodiment of the disclosure:

FIG. 14A illustrates another example detector portion having a partially cylindrical protrusion that can be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

FIG. 14B depicts a front elevation view of the partially cylindrical protrusion of FIG. 14A;

FIGS. 14C through 14E illustrate embodiments of a 55 detector submount;

FIGS. 14F through 14H illustrate embodiment of portions of a detector shell;

FIG. 14I illustrates a cutaway view of an embodiment of a sensor;

FIGS. 15A through 15F illustrate embodiments of sensors that include heat sink features;

FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described herein:

FIG. 15I illustrates an exemplary architecture for a transimpedance-based front-end that may be employed in any of the sensors described herein;

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FIG. **15**J illustrates an exemplary noise model for configuring the transimpedance-based front-ends shown in FIG. **15**I:

FIG. 15K shows different architectures and layouts for various embodiments of a sensor and its detectors;

FIG. **15**L illustrates an exemplary architecture for a switched-capacitor-based front-end that may be employed in any of the sensors described herein;

FIGS. 16A and 16B illustrate embodiments of disposable optical sensors;

FIG. 17 illustrates an exploded view of certain components of an example sensor; and

FIGS. 18 through 22 illustrate various results obtained by an exemplary sensor of the disclosure.

#### DETAILED DESCRIPTION

The present disclosure generally relates to non-invasive medical devices. In the present disclosure, a sensor can measure various blood constituents or analytes noninvasively using multi-stream spectroscopy. In an embodiment, the multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes or percentages thereof (e.g., saturation) based on various 25 combinations of features and components.

In various embodiments, the present disclosure relates to an interface for a noninvasive glucose sensor that comprises a front-end adapted to receive an input signals from optical detectors and provide corresponding output signals. The 30 front-end may comprise, among other things, switched capacitor circuits or transimpedance amplifiers. In an embodiment, the front-end may comprise switched capacitor circuits that are configured to convert the output of sensor's detectors into a digital signal. In another embodiment, the 35 front-end may comprise transimpedance amplifiers. These transimpedance amplifiers may be configured to match one or more photodiodes in a detector based on a noise model that accounts for characteristics, such as the impedance, of the transimpedance amplifier, characteristics of each photo- 40 diode, such as the impedance, and the number of photodiodes coupled to the transimpedance amplifier.

In the present disclosure, the front-ends are employed in a sensor that measures various blood analytes noninvasively using multi-stream spectroscopy. In an embodiment, the 45 multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes, such as glucose, total hemoglobin, methemoglobin, oxygen content, and the like, based on various combinations of features and 50 components.

In an embodiment, a physiological sensor includes a detector housing that can be coupled to a measurement site, such as a patient's finger. The sensor housing can include a curved bed that can generally conform to the shape of the 55 measurement site. In addition, the curved bed can include a protrusion shaped to increase an amount of light radiation from the measurement site. In an embodiment, the protrusion is used to thin out the measurement site. This allows the light radiation to pass through less tissue, and accordingly is 60 attenuated less. In an embodiment, the protrusion can be used to increase the area from which attenuated light can be measured. In an embodiment, this is done through the use of a lens which collects attenuated light exiting the measurement site and focuses onto one or more detectors. The 65 protrusion can advantageously include plastic, including a hard opaque plastic, such as a black or other colored plastic,

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helpful in reducing light noise. In an embodiment, such light noise includes light that would otherwise be detected at a photodetector that has not been attenuated by tissue of the measurement site of a patient sufficient to cause the light to adequately included information indicative of one or more physiological parameters of the patient. Such light noise includes light piping.

In an embodiment, the protrusion can be formed from the curved bed, or can be a separate component that is positionable with respect to the bed. In an embodiment, a lens made from any appropriate material is used as the protrusion. The protrusion can be convex in shape. The protrusion can also be sized and shaped to conform the measurement site into a flat or relatively flat surface. The protrusion can also be sized to conform the measurement site into a rounded surface, such as, for example, a concave or convex surface. The protrusion can include a cylindrical or partially cylindrical shape. The protrusion can be sized or shaped differently for different types of patients, such as an adult, child, or infant. The protrusion can also be sized or shaped differently for different measurement sites, including, for example, a finger, toe, hand, foot, ear, forehead, or the like. The protrusion can thus be helpful in any type of noninvasive sensor. The external surface of the protrusion can include one or more openings or windows. The openings can be made from glass to allow attenuated light from a measurement site, such as a finger, to pass through to one or more detectors. Alternatively, some of all of the protrusion can be a lens, such as a partially cylindrical lens.

The sensor can also include a shielding, such as a metal enclosure as described below or embedded within the protrusion to reduce noise. The shielding can be constructed from a conductive material, such as copper, in the form of a metal cage or enclosure, such as a box. The shielding can include a second set of one or more openings or windows. The second set of openings can be made from glass and allow light that has passed through the first set of windows of the external surface of the protrusion to pass through to one or more detectors that can be enclosed, for example, as described below.

In various embodiments, the shielding can include any substantially transparent, conductive material placed in the optical path between an emitter and a detector. The shielding can be constructed from a transparent material, such as glass, plastic, and the like. The shielding can have an electrically conductive material or coating that is at least partially transparent. The electrically conductive coating can be located on one or both sides of the shielding, or within the body of the shielding. In addition, the electrically conductive coating can be uniformly spread over the shielding or may be patterned. Furthermore, the coating can have a uniform or varying thickness to increase or optimize its shielding effect. The shielding can be helpful in virtually any type of non-invasive sensor that employs spectroscopy.

In an embodiment, the sensor can also include a heat sink. In an embodiment, the heat sink can include a shape that is functional in its ability to dissipate excess heat and aesthetically pleasing to the wearer. For example, the heat sink can be configured in a shape that maximizes surface area to allow for greater dissipation of heat. In an embodiment, the heat sink includes a metalicized plastic, such as plastic including carbon and aluminum to allow for improved thermal conductivity and diffusivity. In an embodiment, the heat sink can advantageously be inexpensively molded into desired shapes and configurations for aesthetic and functional purposes. For example, the shape of the heat sink can

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be a generally curved surface and include one or more fins, undulations, grooves or channels, or combs.

The sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter can include a plurality of sets of optical sources that, 5 in an embodiment, are arranged together as a point source. The various optical sources can emit a sequence of optical radiation pulses at different wavelengths towards a measurement site, such as a patient's finger. Detectors can then detect optical radiation from the measurement site. The 10 optical sources and optical radiation detectors can operate at any appropriate wavelength, including, as discussed herein, infrared, near infrared, visible light, and ultraviolet. In addition, the optical sources and optical radiation detectors can operate at any appropriate wavelength, and such modifications to the embodiments desirable to operate at any such wavelength will be apparent to those skilled in the art.

In certain embodiments, multiple detectors are employed and arranged in a spatial geometry. This spatial geometry provides a diversity of path lengths among at least some of 20 the detectors and allows for multiple bulk and pulsatile measurements that are robust. Each of the detectors can provide a respective output stream based on the detected optical radiation, or a sum of output streams can be provided from multiple detectors. In some embodiments, the sensor 25 can also include other components, such as one or more heat sinks and one or more thermistors.

The spatial configuration of the detectors provides a geometry having a diversity of path lengths among the detectors. For example, a detector in the sensor may comprise multiple detectors that are arranged to have a sufficient difference in mean path length to allow for noise cancellation and noise reduction. In addition, walls may be used to separate individual photodetectors and prevent mixing of detected optical radiation between the different locations on 35 the measurement site. A window may also be employed to facilitate the passing of optical radiation at various wavelengths for measuring glucose in the tissue.

In the present disclosure, a sensor may measure various blood constituents or analytes noninvasively using spectroscopy and a recipe of various features. As disclosed herein, the sensor is capable of non-invasively measuring blood analytes, such as, glucose, total hemoglobin, methemoglobin, oxygen content, and the like. In an embodiment, the spectroscopy used in the sensor can employ visible, infrared 45 and near infrared wavelengths. The sensor may comprise an emitter, a detector, and other components. In some embodiments, the sensor may also comprise other components, such as one or more heat sinks and one or more thermistors.

In various embodiments, the sensor may also be coupled 50 to one or more companion devices that process and/or display the sensor's output. The companion devices may comprise various components, such as a sensor front-end, a signal processor, a display, a network interface, a storage device or memory, etc. 55

A sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter is configured as a point optical source that comprises a plurality of LEDs that emit a sequence of pulses of optical radiation across a spectrum of wavelengths. In some 60 embodiments, the plurality of sets of optical sources may each comprise at least one top-emitting LED and at least one super luminescent LED. In some embodiments, the emitter comprises optical sources that transmit optical radiation in the infrared or near-infrared wavelengths suitable for detecting blood analytes like glucose. In order to achieve the desired SNR for detecting analytes like glucose, the emitter

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may be driven using a progression from low power to higher power. In addition, the emitter may have its duty cycle modified to achieve a desired SNR.

The emitter may be constructed of materials, such as aluminum nitride and may include a heat sink to assist in heat dissipation. A thermistor may also be employed to account for heating effects on the LEDs. The emitter may further comprise a glass window and a nitrogen environment to improve transmission from the sources and prevent oxidative effects.

The sensor can be coupled to one or more monitors that process and/or display the sensor's output. The monitors can include various components, such as a sensor front end, a signal processor, a display, etc.

The sensor can be integrated with a monitor, for example, into a handheld unit including the sensor, a display and user controls. In other embodiments, the sensor can communicate with one or more processing devices. The communication can be via wire(s), cable(s), flex circuit(s), wireless technologies, or other suitable analog or digital communication methodologies and devices to perform those methodologies. Many of the foregoing arrangements allow the sensor to be attached to the measurement site while the device is attached elsewhere on a patient, such as the patient's arm, or placed at a location near the patient, such as a bed, shelf or table. The sensor or monitor can also provide outputs to a storage device or network interface.

Reference will now be made to the Figures to discuss embodiments of the present disclosure.

FIG. 1 illustrates an example of a data collection system 100. In certain embodiments, the data collection system 100 noninvasively measure a blood analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. The system 100 can also measure additional blood analytes and/or other physiological parameters useful in determining a state or trend of wellness of a patient.

The data collection system 100 can be capable of measuring optical radiation from the measurement site. For example, in some embodiments, the data collection system 100 can employ photodiodes defined in terms of area. In an embodiment, the area is from about 1 mm²-5 mm² (or higher) that are capable of detecting about 100 nanoamps (nA) or less of current resulting from measured light at full scale. In addition to having its ordinary meaning, the phrase "at full scale" can mean light saturation of a photodiode amplifier (not shown). Of course, as would be understood by a person of skill in the art from the present disclosure, various other sizes and types of photodiodes can be used with the embodiments of the present disclosure.

The data collection system 100 can measure a range of approximately about 2 nA to about 100 nA full scale. The data collection system 100 can also include sensor frontends that are capable of processing and amplifying current from the detector(s) at signal-to-noise ratios (SNRs) of about 100 decibels (dB) or more, such as about 120 dB in order to measure various desired analytes. The data collection system 100 can operate with a lower SNR if less accuracy is desired for an analyte like glucose.

The data collection system 100 can measure analyte concentrations, including glucose, at least in part by detecting light attenuated by a measurement site 102. The measurement site 102 can be any location on a patient's body, such as a finger, foot, ear lobe, or the like. For convenience, this disclosure is described primarily in the context of a

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finger measurement site 102. However, the features of the embodiments disclosed herein can be used with other measurement sites 102.

In the depicted embodiment, the system 100 includes an optional tissue thickness adjuster or tissue shaper 105, which 5 can include one or more protrusions, bumps, lenses, or other suitable tissue-shaping mechanisms. In certain embodiments, the tissue shaper 105 is a flat or substantially flat surface that can be positioned proximate the measurement site 102 and that can apply sufficient pressure to cause the 10 tissue of the measurement site 102 to be flat or substantially flat. In other embodiments, the tissue shaper 105 is a convex or substantially convex surface with respect to the measurement site 102. Many other configurations of the tissue shaper 105 are possible. Advantageously, in certain embodiments, 15 the tissue shaper 105 reduces thickness of the measurement site 102 while preventing or reducing occlusion at the measurement site 102. Reducing thickness of the site can advantageously reduce the amount of attenuation of the light because there is less tissue through which the light must 20 travel. Shaping the tissue in to a convex (or alternatively concave) surface can also provide more surface area from which light can be detected.

The embodiment of the data collection system 100 shown also includes an optional noise shield 103. In an embodi- 25 ment, the noise shield 103 can be advantageously adapted to reduce electromagnetic noise while increasing the transmittance of light from the measurement site 102 to one or more detectors 106 (described below). For example, the noise shield 103 can advantageously include a conductive coated 30 glass or metal grid electrically communicating with one or more other shields of the sensor 101 or electrically grounded. In an embodiment where the noise shield 103 includes conductive coated glass, the coating can advantageously include indium tin oxide. In an embodiment, the 35 indium tin oxide includes a surface resistivity ranging from approximately 30 ohms per square inch to about 500 ohms per square inch. In an embodiment, the resistivity is approximately 30, 200, or 500 ohms per square inch. As would be understood by a person of skill in the art from the present 40 disclosure, other resistivities can also be used which are less than about 30 ohms or more than about 500 ohms. Other conductive materials transparent or substantially transparent to light can be used instead.

In some embodiments, the measurement site 102 is 45 located somewhere along a non-dominant arm or a non-dominant hand, e.g., a right-handed person's left arm or left hand. In some patients, the non-dominant arm or hand can have less musculature and higher fat content, which can result in less water content in that tissue of the patient. Tissue 50 having less water content can provide less interference with the particular wavelengths that are absorbed in a useful manner by blood analytes like glucose. Accordingly, in some embodiments, the data collection system 100 can be used on a person's non-dominant hand or arm.

The data collection system 100 can include a sensor 101 (or multiple sensors) that is coupled to a processing device or physiological monitor 109. In an embodiment, the sensor 101 and the monitor 109 are integrated together into a single unit. In another embodiment, the sensor 101 and the monitor 60 109 are separate from each other and communicate one with another in any suitable manner, such as via a wired or wireless connection. The sensor 101 and monitor 109 can be attachable and detachable from each other for the convenience of the user or caregiver, for ease of storage, sterility 65 issues, or the like. The sensor 101 and the monitor 109 will now be further described.

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In the depicted embodiment shown in FIG. 1, the sensor 101 includes an emitter 104, a tissue shaper 105, a set of detectors 106, and a front-end interface 108. The emitter 104 can serve as the source of optical radiation transmitted towards measurement site 102. As will be described in further detail below, the emitter 104 can include one or more sources of optical radiation, such as LEDs, laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter 104 includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation.

In some embodiments, the emitter **104** is used as a point optical source, and thus, the one or more optical sources of the emitter **104** can be located within a close distance to each other, such as within about a 2 mm to about 4 mm. The emitters **104** can be arranged in an array, such as is described in U.S. Publication No. 2006/0211924, filed Sep. 21, 2006, titled "Multiple Wavelength Sensor Emitters," the disclosure of which is hereby incorporated by reference in its entirety. In particular, the emitters **104** can be arranged at least in part as described in paragraphs [0061] through [0068] of the aforementioned publication, which paragraphs are hereby incorporated specifically by reference. Other relative spatial relationships can be used to arrange the emitters **104**.

For analytes like glucose, currently available non-invasive techniques often attempt to employ light near the water absorbance minima at or about 1600 nm. Typically, these devices and methods employ a single wavelength or single band of wavelengths at or about 1600 nm. However, to date, these techniques have been unable to adequately consistently measure analytes like glucose based on spectroscopy.

In contrast, the emitter 104 of the data collection system 100 can emit, in certain embodiments, combinations of optical radiation in various bands of interest. For example, in some embodiments, for analytes like glucose, the emitter 104 can emit optical radiation at three (3) or more wavelengths between about 1600 nm to about 1700 nm. In particular, the emitter 104 can emit optical radiation at or about 1610 nm, about 1640 nm, and about 1665 nm. In some circumstances, the use of three wavelengths within about 1600 nm to about 1700 nm enable sufficient SNRs of about 100 dB, which can result in a measurement accuracy of about 20 mg/dL or better for analytes like glucose.

In other embodiments, the emitter 104 can use two (2) wavelengths within about 1600 nm to about 1700 nm to advantageously enable SNRs of about 85 dB, which can result in a measurement accuracy of about 25-30 mg/dL or better for analytes like glucose. Furthermore, in some embodiments, the emitter 104 can emit light at wavelengths above about 1670 nm. Measurements at these wavelengths can be advantageously used to compensate or confirm the contribution of protein, water, and other non-hemoglobin species exhibited in measurements for analytes like glucose conducted between about 1600 nm and about 1700 nm. Of course, other wavelengths and combinations of wavelengths can be used to measure analytes and/or to distinguish other types of tissue, fluids, tissue properties, fluid properties, combinations of the same or the like.

For example, the emitter **104** can emit optical radiation across other spectra for other analytes. In particular, the emitter **104** can employ light wavelengths to measure various blood analytes or percentages (e.g., saturation) thereof. For example, in one embodiment, the emitter **104** can emit optical radiation in the form of pulses at wavelengths about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1640 nm, and about

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1665 nm. In another embodiment, the emitter **104** can emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of 5 course, the emitter **104** can transmit any of a variety of wavelengths of visible or near-infrared optical radiation.

Due to the different responses of analytes to the different wavelengths, certain embodiments of the data collection system 100 can advantageously use the measurements at 10 these different wavelengths to improve the accuracy of measurements. For example, the measurements of water from visible and infrared light can be used to compensate for water absorbance that is exhibited in the near-infrared wavelengths.

As briefly described above, the emitter **104** can include sets of light-emitting diodes (LEDs) as its optical source. The emitter **104** can use one or more top-emitting LEDs. In particular, in some embodiments, the emitter **104** can include top-emitting LEDs emitting light at about 850 nm to 20 1350 nm.

The emitter 104 can also use super luminescent LEDs (SLEDs) or side-emitting LEDs. In some embodiments, the emitter 104 can employ SLEDs or side-emitting LEDs to emit optical radiation at about 1600 nm to about 1800 nm. 25 Emitter 104 can use SLEDs or side-emitting LEDs to transmit near infrared optical radiation because these types of sources can transmit at high power or relatively high power, e.g., about 40 mW to about 100 mW. This higher power capability can be useful to compensate or overcome 30 the greater attenuation of these wavelengths of light in tissue and water. For example, the higher power emission can effectively compensate and/or normalize the absorption signal for light in the mentioned wavelengths to be similar in amplitude and/or effect as other wavelengths that can be 35 detected by one or more photodetectors after absorption. However, the embodiments of the present disclosure do not necessarily require the use of high power optical sources. For example, some embodiments may be configured to measure analytes, such as total hemoglobin (tHb), oxygen 40 saturation (SpO<sub>2</sub>), carboxyhemoglobin, methemoglobin, etc., without the use of high power optical sources like side emitting LEDs. Instead, such embodiments may employ other types of optical sources, such as top emitting LEDs. Alternatively, the emitter **104** can use other types of sources 45 of optical radiation, such as a laser diode, to emit nearinfrared light into the measurement site 102.

In addition, in some embodiments, in order to assist in achieving a comparative balance of desired power output between the LEDs, some of the LEDs in the emitter **104** can 50 have a filter or covering that reduces and/or cleans the optical radiation from particular LEDs or groups of LEDs. For example, since some wavelengths of light can penetrate through tissue relatively well, LEDs, such as some or all of the top-emitting LEDs can use a filter or covering, such as 55 a cap or painted dye. This can be useful in allowing the emitter **104** to use LEDs with a higher output and/or to equalize intensity of LEDs.

The data collection system 100 also includes a driver 111 that drives the emitter 104. The driver 111 can be a circuit 60 or the like that is controlled by the monitor 109. For example, the driver 111 can provide pulses of current to the emitter 104. In an embodiment, the driver 111 drives the emitter 104 in a progressive fashion, such as in an alternating manner. The driver 111 can drive the emitter 104 with a 65 series of pulses of about 1 milliwatt (mW) for some wavelengths that can penetrate tissue relatively well and from

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about 40 mW to about 100 mW for other wavelengths that tend to be significantly absorbed in tissue. A wide variety of other driving powers and driving methodologies can be used in various embodiments.

The driver 111 can be synchronized with other parts of the sensor 101 and can minimize or reduce jitter in the timing of pulses of optical radiation emitted from the emitter 104. In some embodiments, the driver 111 is capable of driving the emitter 104 to emit optical radiation in a pattern that varies by less than about 10 parts-per-million.

The detectors 106 capture and measure light from the measurement site 102. For example, the detectors 106 can capture and measure light transmitted from the emitter 104 that has been attenuated or reflected from the tissue in the measurement site 102. The detectors 106 can output a detector signal 107 responsive to the light captured or measured. The detectors 106 can be implemented using one or more photodiodes, phototransistors, or the like.

In addition, the detectors 106 can be arranged with a spatial configuration to provide a variation of path lengths among at least some of the detectors 106. That is, some of the detectors 106 can have the substantially, or from the perspective of the processing algorithm, effectively, the same path length from the emitter 104. However, according to an embodiment, at least some of the detectors 106 can have a different path length from the emitter 104 relative to other of the detectors 106. Variations in path lengths can be helpful in allowing the use of a bulk signal stream from the detectors 106. In some embodiments, the detectors 106 may employ a linear spacing, a logarithmic spacing, or a two or three dimensional matrix of spacing, or any other spacing scheme in order to provide an appropriate variation in path lengths.

The front end interface 108 provides an interface that adapts the output of the detectors 106, which is responsive to desired physiological parameters. For example, the front end interface 108 can adapt a signal 107 received from one or more of the detectors 106 into a form that can be processed by the monitor 109, for example, by a signal processor 110 in the monitor 109. The front end interface 108 can have its components assembled in the sensor 101, in the monitor 109, in connecting cabling (if used), combinations of the same, or the like. The location of the front end interface 108 can be chosen based on various factors including space desired for components, desired noise reductions or limits, desired heat reductions or limits, and the like.

The front end interface 108 can be coupled to the detectors 106 and to the signal processor 110 using a bus, wire, electrical or optical cable, flex circuit, or some other form of signal connection. The front end interface 108 can also be at least partially integrated with various components, such as the detectors 106. For example, the front end interface 108 can include one or more integrated circuits that are on the same circuit board as the detectors 106. Other configurations can also be used.

The front end interface 108 can be implemented using one or more amplifiers, such as transimpedance amplifiers, that are coupled to one or more analog to digital converters (ADCs) (which can be in the monitor 109), such as a sigma-delta ADC. A transimpedance-based front end interface 108 can employ single-ended circuitry, differential circuitry, and/or a hybrid configuration. A transimpedance-based front end interface 108 can be useful for its sampling rate capability and freedom in modulation/demodulation algorithms. For example, this type of front end interface 108

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can advantageously facilitate the sampling of the ADCs being synchronized with the pulses emitted from the emitter 104.

The ADC or ADCs can provide one or more outputs into multiple channels of digital information for processing by the signal processor 110 of the monitor 109. Each channel can correspond to a signal output from a detector 106.

In some embodiments, a programmable gain amplifier (PGA) can be used in combination with a transimpedance-based front end interface 108. For example, the output of a transimpedance-based front end interface 108 can be output to a PGA that is coupled with an ADC in the monitor 109. A PGA can be useful in order to provide another level of amplification and control of the stream of signals from the detectors 106. Alternatively, the PGA and ADC components can be integrated with the transimpedance-based front end interface 108 in the sensor 101.

In another embodiment, the front end interface 108 can be implemented using switched-capacitor circuits. A switched-capacitor-based front end interface 108 can be useful for, in certain embodiments, its resistor-free design and analog averaging properties. In addition, a switched-capacitor-based front end interface 108 can be useful because it can provide a digital signal to the signal processor 110 in the 25 monitor 109.

As shown in FIG. 1, the monitor 109 can include the signal processor 110 and a user interface, such as a display 112. The monitor 109 can also include optional outputs alone or in combination with the display 112, such as a 30 storage device 114 and a network interface 116. In an embodiment, the signal processor 110 includes processing logic that determines measurements for desired analytes, such as glucose, based on the signals received from the detectors 106. The signal processor 110 can be implemented 35 using one or more microprocessors or subprocessors (e.g., cores), digital signal processors, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), combinations of the same, and the like.

The signal processor 110 can provide various signals that 40 control the operation of the sensor 101. For example, the signal processor 110 can provide an emitter control signal to the driver 111. This control signal can be useful in order to synchronize, minimize, or reduce jitter in the timing of pulses emitted from the emitter 104. Accordingly, this 45 control signal can be useful in order to cause optical radiation pulses emitted from the emitter 104 to follow a precise timing and consistent pattern. For example, when a transimpedance-based front end interface 108 is used, the control signal from the signal processor 110 can provide synchro- 50 nization with the ADC in order to avoid aliasing, cross-talk, and the like. As also shown, an optional memory 113 can be included in the front-end interface 108 and/or in the signal processor 110. This memory 113 can serve as a buffer or storage location for the front-end interface 108 and/or the 55 signal processor 110, among other uses.

The user interface 112 can provide an output, e.g., on a display, for presentation to a user of the data collection system 100. The user interface 112 can be implemented as a touch-screen display, an LCD display, an organic LED 60 display, or the like. In addition, the user interface 112 can be manipulated to allow for measurement on the non-dominant side of patient. For example, the user interface 112 can include a flip screen, a screen that can be moved from one side to another on the monitor 109, or can include an ability 65 to reorient its display indicia responsive to user input or device orientation. In alternative embodiments, the data

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collection system 100 can be provided without a user interface 112 and can simply provide an output signal to a separate display or system.

A storage device 114 and a network interface 116 represent other optional output connections that can be included in the monitor 109. The storage device 114 can include any computer-readable medium, such as a memory device, hard disk storage, EEPROM, flash drive, or the like. The various software and/or firmware applications can be stored in the storage device 114, which can be executed by the signal processor 110 or another processor of the monitor 109. The network interface 116 can be a serial bus port (RS-232/RS-485), a Universal Serial Bus (USB) port, an Ethernet port, a wireless interface (e.g., WiFi such as any 802.1x interface, including an internal wireless card), or other suitable communication device(s) that allows the monitor 109 to communicate and share data with other devices. The monitor 109 can also include various other components not shown, such as a microprocessor, graphics processor, or controller to output the user interface 112, to control data communications, to compute data trending, or to perform other opera-

Although not shown in the depicted embodiment, the data collection system 100 can include various other components or can be configured in different ways. For example, the sensor 101 can have both the emitter 104 and detectors 106 on the same side of the measurement site 102 and use reflectance to measure analytes. The data collection system 100 can also include a sensor that measures the power of light emitted from the emitter 104.

FIGS. 2A through 2D illustrate example monitoring devices 200 in which the data collection system 100 can be housed. Advantageously, in certain embodiments, some or all of the example monitoring devices 200 shown can have a shape and size that allows a user to operate it with a single hand or attach it, for example, to a patient's body or limb. Although several examples are shown, many other monitoring device configurations can be used to house the data collection system 100. In addition, certain of the features of the monitoring devices 200 shown in FIGS. 2A through 2D can be combined with features of the other monitoring devices 200 shown.

Referring specifically to FIG. 2A, an example monitoring device 200A is shown, in which a sensor 201a and a monitor 209a are integrated into a single unit. The monitoring device 200A shown is a handheld or portable device that can measure glucose and other analytes in a patient's finger. The sensor 201a includes an emitter shell 204a and a detector shell 206a. The depicted embodiment of the monitoring device 200A also includes various control buttons 208a and a display 210a.

The sensor 201a can be constructed of white material used for reflective purposes (such as white silicone or plastic), which can increase the usable signal at the detector 106 by forcing light back into the sensor 201a. Pads in the emitter shell 204a and the detector shell 206a can contain separated windows to prevent or reduce mixing of light signals, for example, from distinct quadrants on a patient's finger. In addition, these pads can be made of a relatively soft material, such as a gel or foam, in order to conform to the shape, for example, of a patient's finger. The emitter shell 204a and the detector shell 206a can also include absorbing black or grey material portions to prevent or reduce ambient light from entering into the sensor 201a.

In some embodiments, some or all portions of the emitter shell **204***a* and/or detector shell **206***a* can be detachable and/or disposable. For example, some or all portions of the

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shells 204a and 206a can be removable pieces. The removability of the shells 204a and 206a can be useful for sanitary purposes or for sizing the sensor 201a to different patients. The monitor 209a can include a fitting, slot, magnet, or other connecting mechanism to allow the sensor 201c to be 5 removably attached to the monitor 209a.

The monitoring device 200a also includes optional control buttons 208a and a display 210a that can allow the user to control the operation of the device. For example, a user can operate the control buttons 208a to view one or more 10 measurements of various analytes, such as glucose. In addition, the user can operate the control buttons 208a to view other forms of information, such as graphs, histograms, measurement data, trend measurement data, parameter combination views, wellness indications, and the like. Many 15 parameters, trends, alarms and parameter displays could be output to the display 210a, such as those that are commercially available through a wide variety of noninvasive monitoring devices from Masimo® Corporation of Irvine, Calif.

Furthermore, the controls **208***a* and/or display **210***a* can 20 provide functionality for the user to manipulate settings of the monitoring device **200***a*, such as alarm settings, emitter settings, detector settings, and the like. The monitoring device **200***a* can employ any of a variety of user interface designs, such as frames, menus, touch-screens, and any type 25 of button.

FIG. 2B illustrates another example of a monitoring device 200B. In the depicted embodiment, the monitoring device 200B includes a finger clip sensor 201b connected to a monitor 209b via a cable 212. In the embodiment shown, 30 the monitor 209b includes a display 210b, control buttons 208b and a power button. Moreover, the monitor 209b can advantageously include electronic processing, signal processing, and data storage devices capable of receiving signal data from said sensor 201b, processing the signal data to 35 determine one or more output measurement values indicative of one or more physiological parameters of a monitored patient, and displaying the measurement values, trends of the measurement values, combinations of measurement values, and the like.

The cable 212 connecting the sensor 201b and the monitor 209b can be implemented using one or more wires, optical fiber, flex circuits, or the like. In some embodiments, the cable 212 can employ twisted pairs of conductors in order to minimize or reduce cross-talk of data transmitted from the 45 sensor 201b to the monitor 209b. Various lengths of the cable 212 can be employed to allow for separation between the sensor 201b and the monitor 209b. The cable 212 can be fitted with a connector (male or female) on either end of the cable 212 so that the sensor 201b and the monitor 209b can 50 be connected and disconnected from each other. Alternatively, the sensor 201b and the monitor 209b can be coupled together via a wireless communication link, such as an infrared link, radio frequency channel, or any other wireless communication protocol and channel.

The monitor **209***b* can be attached to the patient. For example, the monitor **209***b* can include a belt clip or straps (see, e.g., FIG. **2**C) that facilitate attachment to a patient's belt, arm, leg, or the like. The monitor **209***b* can also include a fitting, slot, magnet, LEMO snap-click connector, or other connecting mechanism to allow the cable **212** and sensor **201***b* to be attached to the monitor **209**B.

The monitor **209***b* can also include other components, such as a speaker, power button, removable storage or memory (e.g., a flash card slot), an AC power port, and one 65 or more network interfaces, such as a universal serial bus interface or an Ethernet port. For example, the monitor **209***b* 

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can include a display 210b that can indicate a measurement for glucose, for example, in mg/dL. Other analytes and forms of display can also appear on the monitor 209b.

In addition, although a single sensor 201b with a single monitor 209b is shown, different combinations of sensors and device pairings can be implemented. For example, multiple sensors can be provided for a plurality of differing patient types or measurement sites or even patient fingers.

FIG. 2C illustrates yet another example of monitoring device 200C that can house the data collection system 100. Like the monitoring device 200B, the monitoring device 200C includes a finger clip sensor 201c connected to a monitor 209c via a cable 212. The cable 212 can have all of the features described above with respect to FIG. 2B. The monitor 209c can include all of the features of the monitor 200B described above. For example, the monitor 209c includes buttons 208c and a display 210c. The monitor 209c shown also includes straps 214c that allow the monitor 209c to be attached to a patient's limb or the like.

FIG. 2D illustrates vet another example of monitoring device 200D that can house the data collection system 100. Like the monitoring devices 200B and 200C, the monitoring device 200D includes a finger clip sensor 201d connected to a monitor 209d via a cable 212. The cable 212 can have all of the features described above with respect to FIG. 2B. In addition to having some or all of the features described above with respect to FIGS. 2B and 2C, the monitoring device 200D includes an optional universal serial bus (USB) port 216 and an Ethernet port 218. The USB port 216 and the Ethernet port 218 can be used, for example, to transfer information between the monitor 209d and a computer (not shown) via a cable. Software stored on the computer can provide functionality for a user to, for example, view physiological data and trends, adjust settings and download firmware updates to the monitor 209b, and perform a variety of other functions. The USB port 216 and the Ethernet port 218 can be included with the other monitoring devices 200A, 200B, and 200C described above.

FIGS. 3A through 3C illustrate more detailed examples of embodiments of a sensor 301a. The sensor 301a shown can include all of the features of the sensors 100 and 200 described above.

Referring to FIG. 3A, the sensor 301a in the depicted embodiment is a clothespin-shaped clip sensor that includes an enclosure 302a for receiving a patient's finger. The enclosure 302a is formed by an upper section or emitter shell 304a, which is pivotably connected with a lower section or detector shell 306a. The emitter shell 304a can be biased with the detector shell 306a to close together around a pivot point 303a and thereby sandwich finger tissue between the emitter and detector shells 304a, 306a.

In an embodiment, the pivot point 303a advantageously includes a pivot capable of adjusting the relationship between the emitter and detector shells 304a, 306a to effectively level the sections when applied to a tissue site. In another embodiment, the sensor 301a includes some or all features of the finger clip described in U.S. Publication No. 2006/0211924, incorporated above, such as a spring that causes finger clip forces to be distributed along the finger. Paragraphs [0096] through [0105], which describe this feature, are hereby specifically incorporated by reference.

The emitter shell 304a can position and house various emitter components of the sensor 301a. It can be constructed of reflective material (e.g., white silicone or plastic) and/or can be metallic or include metalicized plastic (e.g., including carbon and aluminum) to possibly serve as a heat sink. The emitter shell 304a can also include absorbing opaque mate-

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rial, such as, for example, black or grey colored material, at various areas, such as on one or more flaps 307a, to reduce ambient light entering the sensor 301a.

The detector shell **306***a* can position and house one or more detector portions of the sensor **301***a*. The detector shell **306***a* can be constructed of reflective material, such as white silicone or plastic. As noted, such materials can increase the usable signal at a detector by forcing light back into the tissue and measurement site (see FIG. 1). The detector shell **306***a* can also include absorbing opaque material at various areas, such as lower area **308***a*, to reduce ambient light entering the sensor **301***a*.

Referring to FIGS. 3B and 3C, an example of finger bed 310 is shown in the sensor 301b. The finger bed 310 includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger bed 310 includes one or more ridges or channels 314. Each of the ridges 314 has a generally convex shape that can facilitate increasing traction or gripping of the patient's finger to the finger bed. Advantageously, the ridges 314 can improve the accuracy of spectroscopic analysis in certain embodiments by reducing noise that can result from a measurement site moving or shaking loose inside of the sensor 301a. The ridges 314 can be made from reflective or opaque materials in some 25 embodiments to further increase SNR. In other implementations, other surface shapes can be used, such as, for example, generally flat, concave, or convex finger beds 310.

Finger bed 310 can also include an embodiment of a tissue thickness adjuster or protrusion 305. The protrusion 305 includes a measurement site contact area 370 (see FIG. 3C) that can contact body tissue of a measurement site. The protrusion 305 can be removed from or integrated with the finger bed 310. Interchangeable, different shaped protrusions 305 can also be provided, which can correspond to 35 different finger shapes, characteristics, opacity, sizes, or the like

Referring specifically to FIG. 3C, the contact area 370 of the protrusion 305 can include openings or windows 320, 321, 322, and 323. When light from a measurement site 40 passes through the windows 320, 321, 322, and 323, the light can reach one or more photodetectors (see FIG. 3E). In an embodiment, the windows 320, 321, 322, and 323 mirror specific detector placements layouts such that light can impinge through the protrusion 305 onto the photodetectors. 45 Any number of windows 320, 321, 322, and 323 can be employed in the protrusion 305 to allow light to pass from the measurement site to the photodetectors.

The windows 320, 321, 322, and 323 can also include shielding, such as an embedded grid of wiring or a conduc- 50 tive glass coating, to reduce noise from ambient light or other electromagnetic noise. The windows 320, 321, 322, and 323 can be made from materials, such as plastic or glass. In some embodiments, the windows 320, 321, 322, and 323 can be constructed from conductive glass, such as indium tin 55 oxide (ITO) coated glass. Conductive glass can be useful because its shielding is transparent, and thus allows for a larger aperture versus a window with an embedded grid of wiring. In addition, in certain embodiments, the conductive glass does not need openings in its shielding (since it is transparent), which enhances its shielding performance. For example, some embodiments that employ the conductive glass can attain up to an about 40% to about 50% greater signal than non-conductive glass with a shielding grid. In addition, in some embodiments, conductive glass can be 65 useful for shielding noise from a greater variety of directions than non-conductive glass with a shielding grid.

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Turning to FIG. 3B, the sensor 301a can also include a shielding 315a, such as a metal cage, box, metal sheet, perforated metal sheet, a metal layer on a non-metal material, or the like. The shielding 315a is provided in the depicted embodiment below or embedded within the protrusion 305 to reduce noise. The shielding 315a can be constructed from a conductive material, such as copper. The shielding 315a can include one or more openings or windows (not shown). The windows can be made from glass or plastic to thereby allow light that has passed through the windows 320, 321, 322, and 323 on an external surface of the protrusion 305 (see FIG. 3C) to pass through to one or more photodetectors that can be enclosed or provided below (see FIG. 3E).

In some embodiments, the shielding cage for shielding 315a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding cage can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108.

In an embodiment, the photodetectors can be positioned within or directly beneath the protrusion 305 (see FIG. 3E). In such cases, the mean optical path length from the emitters to the detectors can be reduced and the accuracy of blood analyte measurement can increase. For example, in one embodiment, a convex bump of about 1 mm to about 3 mm in height and about 10 mm<sup>2</sup> to about 60 mm<sup>2</sup> was found to help signal strength by about an order of magnitude versus other shapes. Of course other dimensions and sizes can be employed in other embodiments. Depending on the properties desired, the length, width, and height of the protrusion 305 can be selected. In making such determinations, consideration can be made of protrusion's 305 effect on blood flow at the measurement site and mean path length for optical radiation passing through openings 320, 321, 322, and 323. Patient comfort can also be considered in determining the size and shape of the protrusion.

In an embodiment, the protrusion 305 can include a pliant material, including soft plastic or rubber, which can somewhat conform to the shape of a measurement site. Pliant materials can improve patient comfort and tactility by conforming the measurement site contact area 370 to the measurement site. Additionally, pliant materials can minimize or reduce noise, such as ambient light. Alternatively, the protrusion 305 can be made from a rigid material, such as hard plastic or metal.

Rigid materials can improve measurement accuracy of a blood analyte by conforming the measurement site to the contact area 370. The contact area 370 can be an ideal shape for improving accuracy or reducing noise. Selecting a material for the protrusion 305 can include consideration of materials that do not significantly alter blood flow at the measurement site. The protrusion 305 and the contact area 370 can include a combination of materials with various characteristics.

The contact area 370 serves as a contact surface for the measurement site. For example, in some embodiments, the contact area 370 can be shaped for contact with a patient's finger. Accordingly, the contact area 370 can be sized and shaped for different sizes of fingers. The contact area 370 can be constructed of different materials for reflective purposes as well as for the comfort of the patient. For example,

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the contact area 370 can be constructed from materials having various hardness and textures, such as plastic, gel, foam, and the like.

The formulas and analysis that follow with respect to FIG. 5 provide insight into how selecting these variables can alter 5 transmittance and intensity gain of optical radiation that has been applied to the measurement site. These examples do not limit the scope of this disclosure.

Referring to FIG. 5, a plot 500 is shown that illustrates examples of effects of embodiments of the protrusion 305 on 10 the SNR at various wavelengths of light. As described above, the protrusion 305 can assist in conforming the tissue and effectively reduce its mean path length. In some instances, this effect by the protrusion 305 can have significant impact on increasing the SNR.

According to the Beer Lambert law, a transmittance of light (I) can be expressed as follows:  $I=I_o*e^{-m^*b^*c}$ , where  $I_o$  is the initial power of light being transmitted, m is the path length traveled by the light, and the component "b\*c" corresponds to the bulk absorption of the light at a specific wavelength of light. For light at about 1600 nm to about 1700 nm, for example, the bulk absorption component is generally around 0.7 mm<sup>-1</sup>. Assuming a typical finger thickness of about 12 mm and a mean path length of 20 mm due to tissue scattering, then  $I=I_o*e^{-20^*0.7}$ .

In an embodiment where the protrusion 305 is a convex bump, the thickness of the finger can be reduced to 10 mm (from 12 mm) for some fingers and the effective light mean path is reduced to about 16.6 mm from 20 mm (see box 510). This results in a new transmittance,  $I_1 = I_0 * e^{(-16.6*0.7)}$ . A 30 curve for a typical finger (having a mean path length of 20 mm) across various wavelengths is shown in the plot 500 of FIG. 5. The plot 500 illustrates potential effects of the protrusion 305 on the transmittance. As illustrated, comparing I and  $I_1$  results in an intensity gain of  $e^{(-16.6 * 0.7)}/$  35  $e^{(-20 * 0.7)}$ , which is about a 10 times increase for light in the about 1600 nm to about 1700 nm range. Such an increase can affect the SNR at which the sensor can operate. The foregoing gains can be due at least in part to the about 1600 nm to about 1700 nm range having high values in bulk 40 absorptions (water, protein, and the like), e.g., about 0.7 mm<sup>-1</sup>. The plot **500** also shows improvements in the visible/ near-infrared range (about 600 nm to about 1300 nm).

Turning again to FIGS. 3A through 3C, an example heat sink 350a is also shown. The heat sink 350a can be attached 45 to, or protrude from an outer surface of, the sensor 301a, thereby providing increased ability for various sensor components to dissipate excess heat. By being on the outer surface of the sensor 301a in certain embodiments, the heat sink 350a can be exposed to the air and thereby facilitate 50 more efficient cooling. In an embodiment, one or more of the emitters (see FIG. 1) generate sufficient heat that inclusion of the heat sink 350a can advantageously allows the sensor 301a to remain safely cooled. The heat sink 350a can include one or more materials that help dissipate heat, such 55 as, for example, aluminum, steel, copper, carbon, combinations of the same, or the like. For example, in some embodiments, the emitter shell 304a can include a heat conducting material that is also readily and relatively inexpensively moldable into desired shapes and forms.

In some embodiments, the heat sink **350***a* includes metalicized plastic. The metalicized plastic can include aluminum and carbon, for example. The material can allow for improved thermal conductivity and diffusivity, which can increase commercial viability of the heat sink. In some 65 embodiments, the material selected to construct the heat sink **350***a* can include a thermally conductive liquid crystalline

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polymer, such as CoolPoly® D5506, commercially available from Cool Polymers®, Inc. of Warwick, R.I. Such a material can be selected for its electrically non-conductive and dielectric properties so as, for example, to aid in electrical shielding. In an embodiment, the heat sink 350a provides improved heat transfer properties when the sensor 301a is active for short intervals of less than a full day's use. In an embodiment, the heat sink 350a can advantageously provide improved heat transfers in about three (3) to about four (4) minute intervals, for example, although a heat sink 350a can be selected that performs effectively in shorter or longer intervals.

Moreover, the heat sink 350a can have different shapes and configurations for aesthetic as well as for functional purposes. In an embodiment, the heat sink is configured to maximize heat dissipation, for example, by maximizing surface area. In an embodiment, the heat sink 350a is molded into a generally curved surface and includes one or more fins, undulations, grooves, or channels. The example heat sink 350a shown includes fins 351a (see FIG. 3A).

An alternative shape of a sensor 301b and heat sink 350b is shown in FIG. 3D. The sensor 301b can include some or all of the features of the sensor 301a. For example, the sensor 301b includes an enclosure 302b formed by an 25 emitter shell 304b and a detector shell 306b, pivotably connected about a pivot 303a. The emitter shell 304b can also include absorbing opaque material on one or more flaps 307b, and the detector shell 306a can also include absorbing opaque material at various areas, such as lower area 308b.

However, the shape of the sensor 301b is different in this embodiment. In particular, the heat sink 350b includes comb protrusions 351b. The comb protrusions 351b are exposed to the air in a similar manner to the fins 351a of the heat sink 350a, thereby facilitating efficient cooling of the sensor 301b.

FIG. 3E illustrates a more detailed example of a detector shell 306b of the sensor 301b. The features described with respect to the detector shell 306b can also be used with the detector shell 306a of the sensor 301a.

As shown, the detector shell 306b includes detectors 316. The detectors 316 can have a predetermined spacing 340 from each other, or a spatial relationship among one another that results in a spatial configuration. This spatial configuration can purposefully create a variation of path lengths among detectors 316 and the emitter discussed above.

In the depicted embodiment, the detector shell 316 can hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays can also be useful to detect light piping (e.g., light that bypasses measurement site 102). In the detector shell 316, walls can be provided to separate the individual photodiode arrays to prevent or reduce mixing of light signals from distinct quadrants. In addition, the detector shell 316 can be covered by windows of transparent material, such as glass, plastic, or the like, to allow maximum or increased transmission of power light captured. In various embodiments, the transparent materials used can also be partially transparent or translucent or can otherwise pass some or all of the optical radiation passing through 60 them. As noted, this window can include some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

As further illustrated by FIG. 3E, the detectors 316 can have a spatial configuration of a grid. However, the detectors 316 can be arranged in other configurations that vary the path length. For example, the detectors 316 can be arranged in a linear array, a logarithmic array, a two-dimensional

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array, a zig-zag pattern, or the like. Furthermore, any number of the detectors 316 can be employed in certain embodi-

FIG. 3F illustrates another embodiment of a sensor 301f. The sensor 301f can include some or all of the features of the 5 sensor 301a of FIG. 3A described above. For example, the sensor 301f includes an enclosure 302f formed by an upper section or emitter shell 304f, which is pivotably connected with a lower section or detector shell 306f around a pivot point 303f. The emitter shell 304f can also include absorbing opaque material on various areas, such as on one or more flaps 307f, to reduce ambient light entering the sensor 301f. The detector shell 306f can also include absorbing opaque material at various areas, such as a lower area 308f. The sensor 301f also includes a heat sink 350f, which includes 15 fins 351f.

In addition to these features, the sensor 301f includes a flex circuit cover 360, which can be made of plastic or another suitable material. The flex circuit cover 360 can cover and thereby protect a flex circuit (not shown) that 20 extends from the emitter shell 304f to the detector shell 306f. An example of such a flex circuit is illustrated in U.S. Publication No. 2006/0211924, incorporated above (see FIG. 46 and associated description, which is hereby specifically incorporated by reference). The flex circuit cover 360 25 is shown in more detail below in FIG. 17.

In addition, sensors 301a-f has extra length—extends to second joint on finger-Easier to place, harder to move due to cable, better for light piping.

FIGS. 4A through 4C illustrate example arrangements of 30 a protrusion 405, which is an embodiment of the protrusion 305 described above. In an embodiment, the protrusion 405 can include a measurement site contact area 470. The measurement site contact area 470 can include a surface that molds body tissue of a measurement site, such as a finger, 35 light from a large surface and focus down the light to a into a flat or relatively flat surface.

The protrusion 405 can have dimensions that are suitable for a measurement site such as a patient's finger. As shown, the protrusion 405 can have a length 400, a width 410, and a height 430. The length 400 can be from about 9 to about 40 11 millimeters, e.g., about 10 millimeters. The width 410 can be from about 7 to about 9 millimeters, e.g., about 8 millimeters. The height 430 can be from about 0.5 millimeters to about 3 millimeters, e.g., about 2 millimeters. In an embodiment, the dimensions 400, 410, and 430 can be 45 selected such that the measurement site contact area 470 includes an area of about 80 square millimeters, although larger and smaller areas can be used for different sized tissue for an adult, an adolescent, or infant, or for other considerations.

The measurement site contact area 470 can also include differently shaped surfaces that conform the measurement site into different shapes. For example, the measurement site contact area 470 can be generally curved and/or convex with respect to the measurement site. The measurement site 55 contact area 470 can be other shapes that reduce or even minimize air between the protrusion 405 and/or the measurement site. Additionally, the surface pattern of the measurement site contact area 470 can vary from smooth to bumpy, e.g., to provide varying levels of grip.

In FIGS. 4A and 4C, openings or windows 420, 421, 422, and 423 can include a wide variety of shapes and sizes, including for example, generally square, circular, triangular, or combinations thereof. The windows 420, 421, 422, and 423 can be of non-uniform shapes and sizes. As shown, the 65 windows 420, 421, 422, and 423 can be evenly spaced out in a grid like arrangement. Other arrangements or patterns of

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arranging the windows 420, 421, 422, and 423 are possible. For example, the windows 420, 421, 422, and 423 can be placed in a triangular, circular, or linear arrangement. In some embodiments, the windows 420, 421, 422, and 423 can be placed at different heights with respect to the finger bed 310 of FIG. 3. The windows 420, 421, 422, and 423 can also mimic or approximately mimic a configuration of, or even house, a plurality of detectors.

FIGS. 6A through 6D illustrate another embodiment of a protrusion 605 that can be used as the tissue shaper 105 described above or in place of the protrusions 305, 405 described above. The depicted protrusion 605 is a partially cylindrical lens having a partial cylinder 608 and an extension 610. The partial cylinder 608 can be a half cylinder in some embodiments; however, a smaller or greater portion than half of a cylinder can be used. Advantageously, in certain embodiments, the partially cylindrical protrusion 605 focuses light onto a smaller area, such that fewer detectors can be used to detect the light attenuated by a measurement

FIG. 6A illustrates a perspective view of the partially cylindrical protrusion 605. FIG. 6B illustrates a front elevation view of the partially cylindrical protrusion 605. FIG. 6C illustrates a side view of the partially cylindrical protrusion 605. FIG. 6D illustrates a top view of the partially cylindrical protrusion 605.

Advantageously, in certain embodiments, placing the partially cylindrical protrusion 605 over the photodiodes in any of the sensors described above adds multiple benefits to any of the sensors described above. In one embodiment, the partially cylindrical protrusion 605 penetrates into the tissue and reduces the path length of the light traveling in the tissue, similar to the protrusions described above.

The partially cylindrical protrusion 605 can also collect smaller area. As a result, in certain embodiments, signal strength per area of the photodiode can be increased. The partially cylindrical protrusion 605 can therefore facilitate a lower cost sensor because, in certain embodiments, less photodiode area can be used to obtain the same signal strength. Less photodiode area can be realized by using smaller photodiodes or fewer photodiodes (see, e.g., FIG. 14). If fewer or smaller photodiodes are used, the partially cylindrical protrusion 605 can also facilitate an improved SNR of the sensor because fewer or smaller photodiodes can have less dark current.

The dimensions of the partially cylindrical protrusion 605 can vary based on, for instance, a number of photodiodes used with the sensor. Referring to FIG. 6C, the overall height of the partially cylindrical protrusion 605 (measurement "a") in some implementations is about 1 to about 3 mm. A height in this range can allow the partially cylindrical protrusion 605 to penetrate into the pad of the finger or other tissue and reduce the distance that light travels through the tissue. Other heights, however, of the partially cylindrical protrusion 605 can also accomplish this objective. For example, the chosen height of the partially cylindrical protrusion 605 can be selected based on the size of the measurement site, whether the patient is an adult or child, and so on. In an embodiment, the height of the protrusion 605 is chosen to provide as much tissue thickness reduction as possible while reducing or preventing occlusion of blood vessels in the

Referring to FIG. 6D, the width of the partially cylindrical protrusion 605 (measurement "b") can be about 3 to about 5 mm. In one embodiment, the width is about 4 mm. In one embodiment, a width in this range provides good penetration

of the partially cylindrical protrusion **605** into the tissue to reduce the path length of the light. Other widths, however, of the partially cylindrical protrusion **605** can also accomplish this objective. For example, the width of the partially cylindrical protrusion **605** can vary based on the size of the measurement site, whether the patient is an adult or child, and so on. In addition, the length of the protrusion **605** could be about 10 mm, or about 8 mm to about 12 mm, or smaller than 8 mm or greater than 12 mm.

In certain embodiments, the focal length (f) for the partially cylindrical protrusion 605 can be expressed as:

$$f = \frac{R}{n-1}$$

where R is the radius of curvature of the partial cylinder **608** and n is the index of refraction of the material used. In certain embodiments, the radius of curvature can be between 20 about 1.5 mm and about 2 mm. In another embodiment, the partially cylindrical protrusion **605** can include a material, such as nBK7 glass, with an index of refraction of around 1.5 at 1300 nm, which can provide focal lengths of between about 3 mm and about 4 mm.

A partially cylindrical protrusion 605 having a material with a higher index of refraction such as nSF11 glass (e.g., n=1.75 at 1300 nm) can provide a shorter focal length and possibly a smaller photodiode chip, but can also cause higher reflections due to the index of refraction mismatch 30 with air. Many types of glass or plastic can be used with index of refraction values ranging from, for example, about 1.4 to about 1.9. The index of refraction of the material of the protrusion 605 can be chosen to improve or optimize the light focusing properties of the protrusion 605. A plastic 35 partially cylindrical protrusion 605 could provide the cheapest option in high volumes but can also have some undesired light absorption peaks at wavelengths higher than 1500 nm. Other focal lengths and materials having different indices of refraction can be used for the partially cylindrical protrusion 40 605.

Placing a photodiode at a given distance below the partially cylindrical protrusion 605 can facilitate capturing some or all of the light traveling perpendicular to the lens within the active area of the photodiode (see FIG. 14). 45 Different sizes of the partially cylindrical protrusion 605 can use different sizes of photodiodes. The extension 610 added onto the bottom of the partial cylinder 608 is used in certain embodiments to increase the height of the partially cylindrical protrusion 605. In an embodiment, the added height is 50 such that the photodiodes are at or are approximately at the focal length of the partially cylindrical protrusion 605. In an embodiment, the added height provides for greater thinning of the measurement site. In an embodiment, the added height assists in deflecting light piped through the sensor. This is 55 because light piped around the sensor passes through the side walls of the added height without being directed toward the detectors. The extension 610 can also further facilitate the protrusion 605 increasing or maximizing the amount of light that is provided to the detectors. In some embodiments, 60 the extension 610 can be omitted.

FIG. 6E illustrates another view of the sensor 301f of FIG. 3F, which includes an embodiment of a partially cylindrical protrusion 605b. Like the sensor 301A shown in FIGS. 3B and 3C, the sensor 301f includes a finger bed 310f. The 65 finger bed 310f includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger

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bed 310f also includes the ridges or channels 314 described above with respect to FIGS. 3B and 3C.

The example of finger bed 310*f* shown also includes the protrusion 605*b*, which includes the features of the protrusion 605 described above. In addition, the protrusion 605*b* also includes chamfered edges 607 on each end to provide a more comfortable surface for a finger to slide across (see also FIG. 14D). In another embodiment, the protrusion 605*b* could instead include a single chamfered edge 607 proximal to the ridges 314. In another embodiment, one or both of the chamfered edges 607 could be rounded.

The protrusion **605***b* also includes a measurement site contact area **670** that can contact body tissue of a measurement site. The protrusion **605***b* can be removed from or integrated with the finger bed **310***f*. Interchangeable, differently shaped protrusions **605***b* can also be provided, which can correspond to different finger shapes, characteristics, opacity, sizes, or the like.

FIGS. 7A and 7B illustrate block diagrams of sensors 701
that include example arrangements of conductive glass or
conductive coated glass for shielding. Advantageously, in
certain embodiments, the shielding can provide increased
SNR. The features of the sensors 701 can be implemented
with any of the sensors 101, 201, 301 described above.

25 Although not shown, the partially cylindrical protrusion 605
of FIG. 6 can also be used with the sensors 701 in certain
embodiments.

For example, referring specifically to FIG. 7A, the sensor 701a includes an emitter housing 704a and a detector housing 706. The emitter housing 704a includes LEDs 104. The detector housing 706a includes a tissue bed 710a with an opening or window 703a, the conductive glass 730a, and one or more photodiodes for detectors 106 provided on a submount 707a.

During operation, a finger 102 can be placed on the tissue bed 710a and optical radiation can be emitted from the LEDs 104. Light can then be attenuated as it passes through or is reflected from the tissue of the finger 102. The attenuated light can then pass through the opening 703a in the tissue bed 710a. Based on the received light, the detectors 106 can provide a detector signal 107, for example, to the front end interface 108 (see FIG. 1).

In the depicted embodiment, the conductive glass 730 is provided in the opening 703. The conductive glass 730 can thus not only permit light from the finger to pass to the detectors 106, but it can also supplement the shielding of the detectors 106 from noise. The conductive glass 730 can include a stack or set of layers. In FIG. 7A, the conductive glass 730a is shown having a glass layer 731 proximate the finger 102 and a conductive layer 733 electrically coupled to the shielding 790a.

In an embodiment, the conductive glass 730a can be coated with a conductive, transparent or partially transparent material, such as a thin film of indium tin oxide (ITO). To supplement electrical shielding effects of a shielding enclosure 790a, the conductive glass 730a can be electrically coupled to the shielding enclosure 790a. The conductive glass 730a can be electrically coupled to the shielding 704a based on direct contact or via other connection devices, such as a wire or another component.

The shielding enclosure **790***a* can be provided to encompass the detectors **106** to reduce or prevent noise. For example, the shielding enclosure **790***a* can be constructed from a conductive material, such as copper, in the form of a metal cage. The shielding or enclosure a can include an opaque material to not only reduce electrical noise, but also ambient optical noise.

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In some embodiments, the shielding enclosure 790a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. 5 Furthermore, the shielding enclosure 790a can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108

Referring to FIG. 7B, another block diagram of an 10 example sensor 701b is shown. A tissue bed 710b of the sensor 701b includes a protrusion 705b, which is in the form of a convex bump. The protrusions or tissue shaping materials described above. For example, the protrusion 705b includes 15 a contact area 370 that comes in contact with the finger 102 and which can include one or more openings 703b. One or more components of conductive glass 730b can be provided in the openings 703. For example, in an embodiment, each of the openings 703 can include a separate window of the 20 conductive glass 730b. In an embodiment, a single piece of the conductive glass 730b can used for some or all of the openings 703b. The conductive glass 730b is smaller than the conductive glass 730a in this particular embodiment.

A shielding enclosure 790b is also provided, which can 25 have all the features of the shielding enclosure 790a. The shielding enclosure 790b is smaller than the shielding enclosure 790a; however, a variety of sizes can be selected for the shielding enclosures 790.

In some embodiments, the shielding enclosure 790b can 30 be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding enclosure 790b can also be used 35 to house various other components, such as sigma delta components for various embodiments of front end interfaces 108

FIGS. 8A through 8D illustrate a perspective view, side views, and a bottom elevation view of the conductive glass 40 described above with respect to the sensors 701a, 701b. As shown in the perspective view of FIG. 8A and side view of FIG. 8B, the conductive glass 730 includes the electrically conductive material 733 described above as a coating on the glass layer 731 described above to form a stack. In an 45 embodiment where the electrically conductive material 733 includes indium tin oxide, surface resistivity of the electrically conductive material 733 can range approximately from 30 ohms per square inch to 500 ohms per square inch, or approximately 30, 200, or 500 ohms per square inch. As 50 would be understood by a person of skill in the art from the present disclosure, other resistivities can also be used which are less than 30 ohms or more than 500 ohms. Other transparent, electrically conductive materials can be used as the material 733.

Although the conductive material 733 is shown spread over the surface of the glass layer 731, the conductive material 733 can be patterned or provided on selected portions of the glass layer 731. Furthermore, the conductive material 733 can have uniform or varying thickness depending on a desired transmission of light, a desired shielding effect, and other considerations.

In FIG. 8C, a side view of a conductive glass 830a is shown to illustrate an embodiment where the electrically conductive material 733 is provided as an internal layer 65 between two glass layers 731, 835. Various combinations of integrating electrically conductive material 733 with glass

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are possible. For example, the electrically conductive material 733 can be a layer within a stack of layers. This stack of layers can include one or more layers of glass 731, 835, as well as one or more layers of conductive material 733. The stack can include other layers of materials to achieve desired characteristics.

In FIG. 8D, a bottom perspective view is shown to illustrate an embodiment where a conductive glass 830b can include conductive material 837 that occupies or covers a portion of a glass layer 839. This embodiment can be useful, for example, to create individual, shielded windows for detectors 106, such as those shown in FIG. 3C. The conductive material 837 can be patterned to include an area 838 to allow light to pass to detectors 106 and one or more strips 841 to couple to the shielding 704 of FIG. 7.

Other configurations and patterns for the conductive material can be used in certain embodiments, such as, for example, a conductive coating lining periphery edges, a conductive coating outlaid in a pattern including a grid or other pattern, a speckled conductive coating, coating outlaid in lines in either direction or diagonally, varied thicknesses from the center out or from the periphery in, or other suitable patterns or coatings that balance the shielding properties with transparency considerations.

FIG. 9 depicts an example graph 900 that illustrates comparative results obtained by an example sensor having components similar to those disclosed above with respect to FIGS. 7 and 8. The graph 900 depicts the results of the percentage of transmission of varying wavelengths of light for different types of windows used in the sensors described above.

A line 915 on the graph 900 illustrates example light transmission of a window made from plain glass. As shown, the light transmission percentage of varying wavelengths of light is approximately 90% for a window made from plain glass. A line 920 on the graph 900 demonstrates an example light transmission percentage for an embodiment in which a window is made from glass having an ITO coating with a surface resistivity of 500 ohms per square inch. A line 925 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 200 ohms per square inch. A line 930 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 30 ohms per square inch.

The light transmission percentage for a window with currently available embedded wiring can have a light trans50 mission percentage of approximately 70%. This lower percentage of light transmission can be due to the opacity of the wiring employed in a currently available window with wiring. Accordingly, certain embodiments of glass coatings described herein can employ, for example, ITO coatings with different surface resistivity depending on the desired light transmission, wavelengths of light used for measurement, desired shielding effect, and other criteria.

FIGS. 10A through 10B illustrate comparative noise floors of example implementations of the sensors described above. Noise can include optical noise from ambient light and electro-magnetic noise, for example, from surrounding electrical equipment. In FIG. 10A, a graph 1000 depicts possible noise floors for different frequencies of noise for an embodiment in which one of the sensors described above included separate windows for four (4) detectors 106. One or more of the windows included an embedded grid of wiring as a noise shield. Symbols 1030-1033 illustrate the

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noise floor performance for this embodiment. As can be seen, the noise floor performance can vary for each of the openings and based on the frequency of the noise.

In FIG. 10B, a graph 1050 depicts a noise floor for frequencies of noise 1070 for an embodiment in which the sensor included separate openings for four (4) detectors 106 and one or more windows that include an ITO coating. In this embodiment, a surface resistivity of the ITO used was about 500 ohms per square inch. Symbols 1080-1083 illustrate the noise floor performance for this embodiment. As can be seen, the noise floor performance for this embodiment can vary less for each of the openings and provide lower noise floors in comparison to the embodiment of FIG. 10A

FIG. 11A illustrates an example structure for configuring the set of optical sources of the emitters described above. As shown, an emitter 104 can include a driver 1105, a thermistor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, 25 other thermistors can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such a temperature can also be helpful in correcting for wavelength drift due to changes in water absorption, which can be 30 temperature dependent, thereby providing more accurate data useful in detecting blood analytes like glucose. In addition, using a thermistor or other type of temperature sensitive device may be useful for detecting extreme temperatures at the measurement site that are too hot or too cold. 35 The presence of low perfusion may also be detected, for example, when the finger of a patient has become too cold. Moreover, shifts in temperature at the measurement site can alter the absorption spectrum of water and other tissue in the measurement cite. A thermistor's temperature reading can be 40 used to adjust for the variations in absorption spectrum changes in the measurement site.

The driver 1105 can provide pulses of current to the emitter 1104. In an embodiment, the driver 1105 drives the emitter 1104 in a progressive fashion, for example, in an 45 alternating manner based on a control signal from, for example, a processor (e.g., the processor 110). For example, the driver 1105 can drive the emitter 1104 with a series of pulses to about 1 milliwatt (mW) for visible light to light at about 1300 nm and from about 40 mW to about 100 mW for 50 light at about 1600 nm to about 1700 nm. However, a wide number of driving powers and driving methodologies can be used. The driver 1105 can be synchronized with other parts of the sensor and can minimize or reduce any jitter in the timing of pulses of optical radiation emitted from the emitter 55 1104. In some embodiments, the driver 1105 is capable of driving the emitter 1104 to emit an optical radiation in a pattern that varies by less than about 10 parts-per-million; however other amounts of variation can be used.

The submount 1106 provides a support structure in certain 60 embodiments for aligning the top-emitting LEDs 1102 and the side-emitting LEDs 1104 so that their optical radiation is transmitted generally towards the measurement site. In some embodiments, the submount 1106 is also constructed of aluminum nitride (AlN) or beryllium oxide (BEO) for heat 65 dissipation, although other materials or combinations of materials suitable for the submount 1106 can be used.

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FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring a blood constituent or analyte like glucose. In some embodiments, emitter 104 may be driven in a progressive fashion to minimize noise and increase SNR of sensor 101. For example, emitter 104 may be driven based on a progression of power/current delivered to LEDs 1102 and 1104.

In some embodiments, emitter 104 may be configured to emit pulses centered about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about 1665 nm. In another embodiment, the emitter 104 may emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of course, emitter 104 may be configured to transmit any of a variety of wavelengths of visible, or near-infrared optical radiation.

istor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, other thermistors can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such

For example, as shown in FIG. 11B, the sequence of optical radiation pulses are shown having a logarithmic-like progression in power/current. In some embodiments, the timing of these pulses is based on a cycle of about 400 slots running at 48 kHz (e.g. each time slot may be approximately 0.02 ms or 20 microseconds). An artisan will recognize that term "slots" includes its ordinary meaning, which includes a time period that may also be expressed in terms of a frequency. In the example shown, pulses from top emitting LEDs 1102 may have a pulse width of about 40 time slots (e.g., about 0.8 ms) and an off period of about 4 time slots in between. In addition, pulses from side emitting LEDs 1104 (e.g., or a laser diode) may have a pulse width of about 60 time slots (e.g., about 1.25 ms) and a similar off period of about 4 time slots. A pause of about 70 time slots (e.g. 1.5 ms) may also be provided in order to allow driver circuit 1105 to stabilize after operating at higher current/power.

As shown in FIG. 11B, top emitting LEDs 1102 may be initially driven with a power to approximately 1 mW at a current of about 20-100 mA. Power in these LEDs may also be modulated by using a filter or covering of black dye to reduce power output of LEDs. In this example, top emitting LEDs 1102 may be driven at approximately 0.02 to 0.08 mW. The sequence of the wavelengths may be based on the current requirements of top emitting LEDs 502 for that particular wavelength. Of course, in other embodiments, different wavelengths and sequences of wavelengths may be output from emitter 104.

Subsequently, side emitting LEDs 1104 may be driven at higher powers, such as about 40-100 mW and higher currents of about 600-800 mA. This higher power may be employed in order to compensate for the higher opacity of tissue and water in measurement site 102 to these wavelengths. For example, as shown, pulses at about 1630 nm, about 1660 nm, and about 1615 nm may be output with progressively higher power, such as at about 40 mW, about 50 mW, and about 60 mW, respectively. In this embodiment, the order of wavelengths may be based on the optical characteristics of that wavelength in tissue as well as the

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current needed to drive side emitting LEDs 1104. For example, in this embodiment, the optical pulse at about 1615 nm is driven at the highest power due to its sensitivity in detecting analytes like glucose and the ability of light at this wavelength to penetrate tissue. Of course, different wavelengths and sequences of wavelengths may be output from emitter 104.

As noted, this progression may be useful in some embodiments because it allows the circuitry of driver circuit 1105 to stabilize its power delivery to LEDs 1102 and 1104. 10 Driver circuit 1105 may be allowed to stabilize based on the duty cycle of the pulses or, for example, by configuring a variable waiting period to allow for stabilization of driver circuit 1105. Of course, other variations in power/current and wavelength may also be employed in the present disclosure.

Modulation in the duty cycle of the individual pulses may also be useful because duty cycle can affect the signal noise ratio of the system 100. That is, as the duty cycle is increased so may the signal to noise ratio.

Furthermore, as noted above, driver circuit 1105 may monitor temperatures of the LEDs 1102 and 1104 using the thermistor 1120 and adjust the output of LEDs 1102 and 1104 accordingly. Such a temperature may be to help sensor 101 correct for wavelength drift due to changes in water 25 absorption, which can be temperature dependent.

FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. As shown, the emitter 104 can include components mounted on a substrate 1108 and on submount 30 1106. In particular, top-emitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108. Side emitting LEDS 1104 may be mounted on submount 1106. As noted, side-emitting LEDs 1104 may be included in emitter 104 for emitting near infrared light.

As also shown, the sensor of FIG. 11C may include a thermistor 1120. As noted, the thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to 40 heating. In addition, other thermistors (not shown) can be employed, for example, to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby 45 providing more accurate data useful in detecting blood analytes like glucose.

In some embodiments, the emitter 104 may be implemented without the use of side emitting LEDs. For example, certain blood constituents, such as total hemoglobin, can be 50 measured by embodiments of the disclosure without the use of side emitting LEDs. FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. In particular, an emitter 104 that is configured for a blood constituent, such as total 55 hemoglobin, is shown. The emitter 104 can include components mounted on a substrate 1108. In particular, topemitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108.

As also shown, the emitter of FIG. 11D may include a 60 thermistor 1120. The thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 due to heating.

FIG. 12A illustrates a detector submount 1200 having 65 photodiode detectors that are arranged in a grid pattern on the detector submount 1200 to capture light at different

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quadrants from a measurement site. One detector submount 1200 can be placed under each window of the sensors described above, or multiple windows can be placed over a single detector submount 1200. The detector submount 1200 can also be used with the partially cylindrical protrusion 605 described above with respect to FIG. 6.

The detectors include photodiode detectors 1-4 that are arranged in a grid pattern on the submount **1200** to capture light at different quadrants from the measurement site. As noted, other patterns of photodiodes, such as a linear row, or logarithmic row, can also be employed in certain embodiments

As shown, the detectors 1-4 may have a predetermined spacing from each other, or spatial relationship among one another that result in a spatial configuration. This spatial configuration can be configured to purposefully create a variation of path lengths among detectors 106 and the point light source discussed above.

Detectors may hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays may also be useful to detect light piping (i.e., light that bypasses measurement site 102). As shown, walls may separate the individual photodiode arrays to prevent mixing of light signals from distinct quadrants. In addition, as noted, the detectors may be covered by windows of transparent material, such as glass, plastic, etc., to allow maximum transmission of power light captured. As noted, this window may comprise some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

FIGS. 12B through 12D illustrate a simplified view of exemplary arrangements and spatial configurations of photodiodes for detectors 106. As shown, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a grid pattern on detector submount 1200 to capture light at different quadrants from measurement site 102.

As noted, other patterns of photodiodes may also be employed in embodiments of the present disclosure, including, for example, stacked or other configurations recognizable to an artisan from the disclosure herein. For example, detectors 106 may be arranged in a linear array, a logarithmic array, a two-dimensional array, and the like. Furthermore, an artisan will recognize from the disclosure herein that any number of detectors 106 may be employed by embodiments of the present disclosure.

For example, as shown in FIG. 12B, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a substantially linear configuration on submount 1200. In this embodiment shown, photodiode detectors 1-4 are substantially equally spaced apart (e.g., where the distance D is substantially the same between detectors 1-4).

In FIG. 12C, photodiode detectors 1-4 may be arranged in a substantially linear configuration on submount 1200, but may employ a substantially progressive, substantially logarithmic, or substantially semi-logarithmic spacing (e.g., where distances D1>D2>D3). This arrangement or pattern may be useful for use on a patient's finger and where the thickness of the finger gradually increases.

In FIG. 12D, a different substantially grid pattern on submount 1200 of photodiode detectors 1-4 is shown. As noted, other patterns of detectors may also be employed in embodiments of the present invention.

FIGS. 12E through 12H illustrate several embodiments of photodiodes that may be used in detectors 106. As shown in these figures, a photodiode 1202 of detector 106 may comprise a plurality of active areas 1204. These active areas

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204 may be coupled together via a common cathode 1206 or anode 1208 in order to provide a larger effective detection

In particular, as shown in FIG. 12E, photodiode 1202 may comprise two (2) active areas **1204***a* and **1204***b*. In FIG. **12**F, 5 photodiode 1202 may comprise four (4) active areas 1204c-f. In FIG. 12G, photodiode 1202 may comprise three (3) active areas 1204g-i. In FIG. 12H, photodiode 1202 may comprise nine (9) active areas 1204j-r. The use of smaller active areas may be useful because smaller active areas can 10 be easier to fabricate and can be fabricated with higher purity. However, one skilled in the art will recognize that various sizes of active areas may be employed in the photodiode 1202.

FIG. 13 illustrates an example multi-stream process 1300. 15 The multi-stream process 1300 can be implemented by the data collection system 100 and/or by any of the sensors described above. As shown, a control signal from a signal processor 1310 controls a driver 1305. In response, an emitter 1304 generates a pulse sequence 1303 from its 20 emitter (e.g., its LEDs) into a measurement site or sites 1302. As described above, in some embodiments, the pulse sequence 1303 is controlled to have a variation of about 10 parts per million or less. Of course, depending on the analyte desired, the tolerated variation in the pulse sequence 1303 25 can be greater (or smaller).

In response to the pulse sequence 1300, detectors 1 to n (n being an integer) in a detector 1306 capture optical radiation from the measurement site 1302 and provide respective streams of output signals. Each signal from one of 30 detectors 1-n can be considered a stream having respective time slots corresponding to the optical pulses from emitter sets 1-n in the emitter 1304. Although n emitters and n detectors are shown, the number of emitters and detectors need not be the same in certain implementations.

A front end interface 1308 can accept these multiple streams from detectors 1-n and deliver one or more signals or composite signal(s) back to the signal processor 1310. A stream from the detectors 1-n can thus include measured light intensities corresponding to the light pulses emitted 40 from the emitter 1304.

The signal processor 1310 can then perform various calculations to measure the amount of glucose and other analytes based on these multiple streams of signals. In order analytes like glucose, a primer on the spectroscopy employed in these embodiments will now be provided.

Spectroscopy is premised upon the Beer-Lambert law. According to this law, the properties of a material, e.g., glucose present in a measurement site, can be deterministi- 50 cally calculated from the absorption of light traveling through the material. Specifically, there is a logarithmic relation between the transmission of light through a material and the concentration of a substance and also between the transmission and the length of the path traveled by the light. 55 As noted, this relation is known as the Beer-Lambert law.

The Beer-Lambert law is usually written as:

Absorbance A=m\*b\*c, where:

m is the wavelength-dependent molar absorptivity coefficient (usually expressed in units of M<sup>-1</sup> cm<sup>-1</sup>):

b is the mean path length; and

c is the analyte concentration (e.g., the desired parameter). In spectroscopy, instruments attempt to obtain the analyte concentration (c) by relating absorbance (A) to transmittance (T). Transmittance is a proportional value defined as:

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I is the light intensity measured by the instrument from the measurement site; and

I<sub>a</sub> is the initial light intensity from the emitter.

Absorbance (A) can be equated to the transmittance (T) by the equation:

 $A=-\log T$ 

Therefore, substituting equations from above:

 $A = -\log(I/I_o)$ 

In view of this relationship, spectroscopy thus relies on a proportional-based calculation of  $-\log(I/I_a)$  and solving for analyte concentration (c).

Typically, in order to simplify the calculations, spectroscopy will use detectors that are at the same location in order to keep the path length (b) a fixed, known constant. In addition, spectroscopy will employ various mechanisms to definitively know the transmission power (I<sub>o</sub>), such as a photodiode located at the light source. This architecture can be viewed as a single channel or single stream sensor, because the detectors are at a single location.

However, this scheme can encounter several difficulties in measuring analytes, such as glucose. This can be due to the high overlap of absorption of light by water at the wavelengths relevant to glucose as well as other factors, such as high self-noise of the components.

Embodiments of the present disclosure can employ a different approach that in part allows for the measurement of analytes like glucose. Some embodiments can employ a bulk, non-pulsatile measurement in order to confirm or validate a pulsatile measurement. In addition, both the non-pulsatile and pulsatile measurements can employ, among other things, the multi-stream operation described above in order to attain sufficient SNR. In particular, a single light source having multiple emitters can be used to transmit light to multiple detectors having a spatial configuration.

A single light source having multiple emitters can allow for a range of wavelengths of light to be used. For example, visible, infrared, and near infrared wavelengths can be employed. Varying powers of light intensity for different wavelengths can also be employed.

Secondly, the use of multiple-detectors in a spatial conto help explain how the signal processor 1310 can measure 45 figuration allow for a bulk measurement to confirm or validate that the sensor is positioned correctly. This is because the multiple locations of the spatial configuration can provide, for example, topology information that indicates where the sensor has been positioned. Currently available sensors do not provide such information. For example, if the bulk measurement is within a predetermined range of values, then this can indicate that the sensor is positioned correctly in order to perform pulsatile measurements for analytes like glucose. If the bulk measurement is outside of a certain range or is an unexpected value, then this can indicate that the sensor should be adjusted, or that the pulsatile measurements can be processed differently to compensate, such as using a different calibration curve or adjusting a calibration curve. This feature and others allow the embodiments to achieve noise cancellation and noise reduction, which can be several times greater in magnitude that what is achievable by currently available technology.

> In order to help illustrate aspects of the multi-stream measurement approach, the following example derivation is 65 provided. Transmittance (T) can be expressed as:

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In terms of light intensity, this equation can also be rewritten as:

$$I/I_{o} = e^{-m*b*c}$$

Or, at a detector, the measured light (I) can be expressed  $_{5}$  as:

$$I = I_o *e^{-m*b*c}$$

As noted, in the present disclosure, multiple detectors (1 to n) can be employed, which results in  $I_1 \ldots I_n$  streams of measurements. Assuming each of these detectors have their own path lengths,  $b_1 \ldots b_n$ , from the light source, the measured light intensities can be expressed as:

$$I_n = I_o * e^{-m * b_n * c}$$

The measured light intensities at any two different detectors can be referenced to each other. For example:

$$I_1/I_n = (I_o * e^{-mb_1 c})/(I_o * e^{-mb_n c})$$

As can be seen, the terms, I<sub>o</sub>, cancel out and, based on exponent algebra, the equation can be rewritten as:

$$I_1/I_n = e^{-m(b_1-b_n)c}$$

From this equation, the analyte concentration (c) can now be derived from bulk signals  $I_1 \ldots I_n$  and knowing the respective mean path lengths  $b_1$  and  $b_n$ . This scheme also 25 allows for the cancelling out of  $I_o$ , and thus, noise generated by the emitter **1304** can be cancelled out or reduced. In addition, since the scheme employs a mean path length difference, any changes in mean path length and topological variations from patient to patient are easily accounted. 30 Furthermore, this bulk-measurement scheme can be extended across multiple wavelengths. This flexibility and other features allow embodiments of the present disclosure to measure blood analytes like glucose.

For example, as noted, the non-pulsatile, bulk measurements can be combined with pulsatile measurements to more accurately measure analytes like glucose. In particular, the non-pulsatile, bulk measurement can be used to confirm or validate the amount of glucose, protein, etc. in the pulsatile measurements taken at the tissue at the measurement site(s) 40 1302. The pulsatile measurements can be used to measure the amount of glucose, hemoglobin, or the like that is present in the blood. Accordingly, these different measurements can be combined to thus determine analytes like blood glucose.

FIG. 14A illustrates an embodiment of a detector submount 1400a positioned beneath the partially cylindrical protrusion 605 of FIG. 6 (or alternatively, the protrusion 605b). The detector submount 1400a includes two rows 1408a of detectors 1410a. The partially cylindrical protrusion 605 can facilitate reducing the number and/or size of 50 detectors used in a sensor because the protrusion 605 can act as a lens that focuses light onto a smaller area.

To illustrate, in some sensors that do not include the partially cylindrical protrusion 605, sixteen detectors can be used, including four rows of four detectors each. Multiple 55 rows of detectors can be used to measure certain analytes, such as glucose or total hemoglobin, among others. Multiple rows of detectors can also be used to detect light piping (e.g., light that bypasses the measurement site). However, using more detectors in a sensor can add cost, complexity, and 60 noise to the sensor.

Applying the partially cylindrical protrusion **605** to such a sensor, however, could reduce the number of detectors or rows of detectors used while still receiving the substantially same amount of light, due to the focusing properties of the 65 protrusion **605** (see FIG. **14B**). This is the example situation illustrated in FIG. **14**—two rows **1408***a* of detectors **1410***a* 

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are used instead of four. Advantageously, in certain embodiments, the resulting sensor can be more cost effective, have less complexity, and have an improved SNR, due to fewer and/or smaller photodiodes.

In other embodiments, using the partially cylindrical protrusion 605 can allow the number of detector rows to be reduced to one or three rows of four detectors. The number of detectors in each row can also be reduced. Alternatively, the number of rows might not be reduced but the size of the detectors can be reduced. Many other configurations of detector rows and sizes can also be provided.

FIG. 14B depicts a front elevation view of the partially cylindrical protrusion 605 (or alternatively, the protrusion 605b) that illustrates how light from emitters (not shown) can be focused by the protrusion 605 onto detectors. The protrusion 605 is placed above a detector submount 1400b having one or more detectors 1410b disposed thereon. The submount 1400b can include any number of rows of detectors 1410, although one row is shown.

Light, represented by rays 1420, is emitted from the emitters onto the protrusion 605. These light rays 1420 can be attenuated by body tissue (not shown). When the light rays 1420 enter the protrusion 605, the protrusion 605 acts as a lens to refract the rays into rays 1422. This refraction is caused in certain embodiments by the partially cylindrical shape of the protrusion 605. The refraction causes the rays 1422 to be focused or substantially focused on the one or more detectors 1410b. Since the light is focused on a smaller area, a sensor including the protrusion 605 can include fewer detectors to capture the same amount of light compared with other sensors.

FIG. 14C illustrates another embodiment of a detector submount 1400c, which can be disposed under the protrusion 605b (or alternatively, the protrusion 605). The detector submount 1400c includes a single row 1408c of detectors 1410c. The detectors are electrically connected to conductors 1412c, which can be gold, silver, copper, or any other suitable conductive material.

The detector submount 1400c is shown positioned under the protrusion 605b in a detector subassembly 1450 illustrated in FIG. 14D. A top-down view of the detector subassembly 1450 is also shown in FIG. 14E. In the detector subassembly 1450, a cylindrical housing 1430 is disposed on the submount 1400c. The cylindrical housing 1430 includes a transparent cover 1432, upon which the protrusion 605b is disposed. Thus, as shown in FIG. 14D, a gap 1434 exists between the detectors 1410c and the protrusion 605b. The height of this gap 1434 can be chosen to increase or maximize the amount of light that impinges on the detectors 1410c.

The cylindrical housing 1430 can be made of metal, plastic, or another suitable material. The transparent cover 1432 can be fabricated from glass or plastic, among other materials. The cylindrical housing 1430 can be attached to the submount 1400c at the same time or substantially the same time as the detectors 1410c to reduce manufacturing costs. A shape other than a cylinder can be selected for the housing 1430 in various embodiments.

In certain embodiments, the cylindrical housing 1430 (and transparent cover 1432) forms an airtight or substantially airtight or hermetic seal with the submount 1400c. As a result, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c from fluids and vapors that can cause corrosion. Advantageously, in certain embodiments, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c more effectively than cur-

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rently-available resin epoxies, which are sometimes applied to solder joints between conductors and detectors.

In embodiments where the cylindrical housing 1430 is at least partially made of metal, the cylindrical housing 1430 can provide noise shielding for the detectors 1410c. For 5 example, the cylindrical housing 1430 can be soldered to a ground connection or ground plane on the submount 1400c. which allows the cylindrical housing 1430 to reduce noise. In another embodiment, the transparent cover 1432 can include a conductive material or conductive layer, such as conductive glass or plastic. The transparent cover 1432 can include any of the features of the noise shields 790 described

The protrusion 605b includes the chamfered edges  $607_{15}$ described above with respect to FIG. 6E. These chamfered edges 607 can allow a patient to more comfortably slide a finger over the protrusion 605b when inserting the finger into the sensor 301f.

which includes the detectors 1410c on the substrate 1400c. The substrate 1400c is enclosed by a shielding enclosure 1490, which can include the features of the shielding enclosures 790a, 790b described above (see also FIG. 17). The shielding enclosure 1490 can be made of metal. The shield-25 ing enclosure 1490 includes a window 1492a above the detectors 1410c, which allows light to be transmitted onto the detectors 1410c.

A noise shield 1403 is disposed above the shielding enclosure 1490. The noise shield 1403, in the depicted 30 embodiment, includes a window 1492a corresponding to the window 1492a. Each of the windows 1492a, 1492b can include glass, plastic, or can be an opening without glass or plastic. In some embodiments, the windows 1492a, 1492b may be selected to have different sizes or shapes from each 35

The noise shield 1403 can include any of the features of the conductive glass described above. In the depicted embodiment, the noise shield 1403 extends about threequarters of the length of the detector shell 306f. In other 40 embodiments, the noise shield 1403 could be smaller or larger. The noise shield 1403 could, for instance, merely cover the detectors 1410c, the submount 1400c, or a portion thereof. The noise shield 1403 also includes a stop 1413 for positioning a measurement site within the sensor 301f. 45 Advantageously, in certain embodiments, the noise shield 1403 can reduce noise caused by light piping.

A thermistor 1470 is also shown. The thermistor 1470 is attached to the submount 1400c and protrudes above the noise shield 1403. As described above, the thermistor 1470 50 can be employed to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby providing more accurate data useful in detecting blood analytes like 55 glucose.

In the depicted embodiment, the detectors 1410c are not enclosed in the cylindrical housing 1430. In an alternative embodiment, the cylindrical housing 1430 encloses the detectors 1410c and is disposed under the noise shield 1403. 60 In another embodiment, the cylindrical housing 1430 encloses the detectors 1410c and the noise shield 1403 is not used. If both the cylindrical housing 1403 and the noise shield 1403 are used, either or both can have noise shielding

FIG. 14G illustrates the detector shell 306f of FIG. 14F, with the finger bed 310f disposed thereon. FIG. 14H illus38

trates the detector shell 306f of FIG. 14G, with the protrusion 605b disposed in the finger bed 310f.

FIG. 14I illustrates a cutaway view of the sensor 301f. Not all features of the sensor 301f are shown, such as the protrusion 605b. Features shown include the emitter and detector shells 304f, 306f, the flaps 307f, the heat sink 350f and fins 351f, the finger bed 310f, and the noise shield 1403.

In addition to these features, emitters 1404 are depicted in the emitter shell 304f. The emitters 1404 are disposed on a submount 1401, which is connected to a circuit board 1419. The emitters 1404 are also enclosed within a cylindrical housing 1480. The cylindrical housing 1480 can include all of the features of the cylindrical housing 1430 described above. For example, the cylindrical housing 1480 can be made of metal, can be connected to a ground plane of the submount 1401 to provide noise shielding, and can include a transparent cover 1482.

The cylindrical housing 1480 can also protect the emitters FIG. 14F illustrates a portion of the detector shell 306f, 20 1404 from fluids and vapors that can cause corrosion. Moreover, the cylindrical housing 1480 can provide a gap between the emitters 1404 and the measurement site (not shown), which can allow light from the emitters 1404 to even out or average out before reaching the measurement

> The heat sink 350f, in addition to including the fins 351f, includes a protuberance 352f that extends down from the fins **351** f and contacts the submount **1401**. The protuberance 352f can be connected to the submount 1401, for example, with thermal paste or the like. The protuberance 352f can sink heat from the emitters 1404 and dissipate the heat via the fins **351***f*.

> FIGS. 15A and 15B illustrate embodiments of sensor portions 1500A, 15008 that include alternative heat sink features to those described above. These features can be incorporated into any of the sensors described above. For example, any of the sensors above can be modified to use the heat sink features described below instead of or in addition to the heat sink features of the sensors described above.

> The sensor portions 1500A, 1500B shown include LED emitters 1504; however, for ease of illustration, the detectors have been omitted. The sensor portions 1500A, 1500B shown can be included, for example, in any of the emitter shells described above.

> The LEDs 1504 of the sensor portions 1500A, 1500B are connected to a substrate or submount 1502. The submount 1502 can be used in place of any of the submounts described above. The submount 1502 can be a non-electrically conducting material made of any of a variety of materials, such as ceramic, glass, or the like. A cable 1512 is attached to the submount 1502 and includes electrical wiring 1514, such as twisted wires and the like, for communicating with the LEDs 1504. The cable 1512 can correspond to the cables 212 described above.

> Although not shown, the cable 1512 can also include electrical connections to a detector. Only a portion of the cable 1512 is shown for clarity. The depicted embodiment of the cable 1512 includes an outer jacket 1510 and a conductive shield 1506 disposed within the outer jacket 1510. The conductive shield 1506 can be a ground shield or the like that is made of a metal such as braided copper or aluminum. The conductive shield **1506** or a portion of the conductive shield 1506 can be electrically connected to the submount 1502 and can reduce noise in the signal generated by the sensor 1500A, 1500B by reducing RF coupling with the wires 1514. In alternative embodiments, the cable 1512 does not have a conductive shield. For example, the cable 1512

could be a twisted pair cable or the like, with one wire of the twisted pair used as a heat sink.

Referring specifically to FIG. 15A, in certain embodiments, the conductive shield 1506 can act as a heat sink for the LEDs 1504 by absorbing thermal energy from the LEDs 5 1504 and/or the submount 1502. An optional heat insulator 1520 in communication with the submount 1502 can also assist with directing heat toward the conductive shield 1506. The heat insulator 1520 can be made of plastic or another suitable material. Advantageously, using the conductive 10 shield 1506 in the cable 1512 as a heat sink can, in certain embodiments, reduce cost for the sensor.

Referring to FIG. 15B, the conductive shield 1506 can be attached to both the submount 1502 and to a heat sink layer 1530 sandwiched between the submount 1502 and the 15 optional insulator 1520. Together, the heat sink layer 1530 and the conductive shield 1506 in the cable 1512 can absorb at least part of the thermal energy from the LEDs and/or the submount 1502.

FIGS. 15C and 15D illustrate implementations of a sensor 20 portion 1500C that includes the heat sink features of the sensor portion 1500A described above with respect to FIG. 15A. The sensor portion 1500C includes the features of the sensor portion 1500A, except that the optional insulator 1520 is not shown. FIG. 15D is a side cutaway view of the 25 sensor portion 1500C that shows the emitters 1504.

The cable 1512 includes the outer jacket 1510 and the conductive shield 1506. The conductive shield 1506 is soldered to the submount 1502, and the solder joint 1561 is shown. In some embodiments, a larger solder joint 1561 can 30 assist with removing heat more rapidly from the emitters 1504. Various connections 1563 between the submount 1502 and a circuit board 1519 are shown. In addition, a cylindrical housing 1580, corresponding to the cylindrical housing 1480 of FIG. 14I, is shown protruding through the circuit board 35 1519. The emitters 1504 are enclosed in the cylindrical housing 1580.

FIGS. 15E and 15F illustrate implementations of a sensor portion 1500E that includes the heat sink features of the sensor portion 1500B described above with respect to FIG. 40 15B. The sensor portion 1500E includes the heat sink layer 1530. The heat sink layer 1530 can be a metal plate, such as a copper plate or the like. The optional insulator 1520 is not shown. FIG. 15F is a side cutaway view of the sensor portion 1500E that shows the emitters 1504.

In the depicted embodiment, the conductive shield 1506 of the cable 1512 is soldered to the heat sink layer 1530 instead of the submount 1502. The solder joint 1565 is shown. In some embodiments, a larger solder joint 1565 can assist with removing heat more rapidly from the emitters 50 1504. Various connections 1563 between the submount 1502 and a circuit board 1519 are shown. In addition, the cylindrical housing 1580 is shown protruding through the circuit board 1519. The emitters 1504 are enclosed in the cylindrical housing 1580.

FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described above with respect to FIGS. 1 through 15F. Referring to FIG. 15G, the circuit board 1519 includes a female connector 1575 that mates with a male connector 1577 connected to a 60 daughter board 1587. The daughter board 1587 includes connections to the electrical wiring 1514 of the cable 1512. The connected boards 1519, 1587 are shown in FIG. 15H. Also shown is a hole 1573 that can receive the cylindrical housing 1580 described above.

Advantageously, in certain embodiments, using a daughter board 1587 to connect to the circuit board 1519 can

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enable connections to be made more easily to the circuit board **1519**. In addition, using separate boards can be easier to manufacture than a single circuit board **1519** with all connections soldered to the circuit board **1519**.

FIG. 15I illustrates an exemplary architecture for frontend interface 108 as a transimpedance-based front-end. As noted, front-end interfaces 108 provide an interface that adapts the output of detectors 106 into a form that can be handled by signal processor 110. As shown in this figure, sensor 101 and front-end interfaces 108 may be integrated together as a single component, such as an integrated circuit. Of course, one skilled in the art will recognize that sensor 101 and front end interfaces 108 may comprise multiple components or circuits that are coupled together.

Front-end interfaces 108 may be implemented using transimpedance amplifiers that are coupled to analog to digital converters in a sigma delta converter. In some embodiments, a programmable gain amplifier (PGA) can be used in combination with the transimpedance-based front-ends. For example, the output of a transimpedance-based front-end may be output to a sigma-delta ADC that comprises a PGA. A PGA may be useful in order to provide another level of amplification and control of the stream of signals from detectors 106. The PGA may be an integrated circuit or built from a set of micro-relays. Alternatively, the PGA and ADC components in converter 900 may be integrated with the transimpedance-based front-end in sensor 101.

Due to the low-noise requirements for measuring blood analytes like glucose and the challenge of using multiple photodiodes in detector 106, the applicants developed a noise model to assist in configuring front-end 108. Conventionally, those skilled in the art have focused on optimizing the impedance of the transimpedance amplifiers to minimize noise.

However, the following noise model was discovered by the applicants:

Noise=
$$\sqrt{aR+bR^2}$$
, where:

aR is characteristic of the impedance of the transimpedance amplifier; and

bR<sup>2</sup> is characteristic of the impedance of the photodiodes in detector and the number of photodiodes in detector 106.

The foregoing noise model was found to be helpful at least in part due to the high SNR required to measure analytes like glucose. However, the foregoing noise model was not previously recognized by artisans at least in part because, in conventional devices, the major contributor to noise was generally believed to originate from the emitter or the LEDs. Therefore, artisans have generally continued to focus on reducing noise at the emitter.

However, for analytes like glucose, the discovered noise model revealed that one of the major contributors to noise was generated by the photodiodes. In addition, the amount 55 of noise varied based on the number of photodiodes coupled to a transimpedance amplifier. Accordingly, combinations of various photodiodes from different manufacturers, different impedance values with the transimpedance amplifiers, and different numbers of photodiodes were tested as possible 60 embodiments.

In some embodiments, different combinations of transimpedance to photodiodes may be used. For example, detectors 1-4 (as shown, e.g., in FIG. 12A) may each comprise four photodiodes. In some embodiments, each detector of four photodiodes may be coupled to one or more transimpedance amplifiers. The configuration of these amplifiers may be set according to the model shown in FIG. 15J.

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Alternatively, each of the photodiodes may be coupled to its own respective transimpedance amplifier. For example, transimpedance amplifiers may be implemented as integrated circuits on the same circuit board as detectors 1-4. In this embodiment, the transimpedance amplifiers may be 5 grouped into an averaging (or summing) circuit, which are known to those skilled in the art, in order to provide an output stream from the detector. The use of a summing amplifier to combine outputs from several transimpedance amplifiers into a single, analog signal may be helpful in 10 improving the SNR relative to what is obtainable from a single transimpedance amplifier. The configuration of the transimpedance amplifiers in this setting may also be set according to the model shown in FIG. 15J.

As yet another alternative, as noted above with respect to 15 FIGS. 12E through 12H, the photodiodes in detectors 106 may comprise multiple active areas that are grouped together. In some embodiments, each of these active areas may be provided its own respective transimpedance. This form of pairing may allow a transimpedance amplifier to be 20 better matched to the characteristics of its corresponding photodiode or active area of a photodiode.

As noted, FIG. **15**J illustrates an exemplary noise model that may be useful in configuring transimpedance amplifiers. As shown, for a given number of photodiodes and a desired 25 SNR, an optimal impedance value for a transimpedance amplifier could be determined.

For example, an exemplary "4 PD per stream" sensor 1502 is shown where detector 106 comprises four photodiodes 1502. The photodiodes 1502 are coupled to a single 30 transimpedance amplifier 1504 to produce an output stream 1506. In this example, the transimpedance amplifier comprises 10 M $\Omega$  resistors 1508 and 1510. Thus, output stream 1506 is produced from the four photodiodes (PD) 1502. As shown in the graph of FIG. 15J, the model indicates that 35 resistance values of about 10 M $\Omega$  may provide an acceptable SNR for analytes like glucose.

However, as a comparison, an exemplary "1 PD per stream" sensor **1512** is also shown in FIG. **15J**. In particular, sensor **1512** may comprise a plurality of detectors **106** that 40 each comprises a single photodiode **1514**. In addition, as shown for this example configuration, each of photodiodes **1514** may be coupled to respective transimpedance amplifiers **1516**, e.g., 1 PD per stream. Transimpedance amplifiers are shown having 40 M $\Omega$  resistors **1518**. As also shown in 45 the graph of FIG. **15J**, the model illustrates that resistance values of 40 M $\Omega$  for resistors **1518** may serve as an alternative to the 4 photodiode per stream architecture of sensor **1502** described above and yet still provide an equivalent SNR.

Moreover, the discovered noise model also indicates that utilizing a 1 photodiode per stream architecture like that in sensor **1512** may provide enhanced performance because each of transimpedance amplifiers **1516** can be tuned or optimized to its respective photodiodes **1518**. In some 55 embodiments, an averaging component **1520** may also be used to help cancel or reduce noise across photodiodes **1518**.

For purposes of illustration, FIG. 15K shows different architectures (e.g., four PD per stream and one PD per stream) for various embodiments of a sensor and how 60 components of the sensor may be laid out on a circuit board or substrate. For example, sensor 1522 may comprise a "4 PD per stream" architecture on a submount 700 in which each detector 106 comprises four (4) photodiodes 1524. As shown for sensor 1522, the output of each set of four 65 photodiodes 1524 is then aggregated into a single transimpedance amplifier 1526 to produce a signal.

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As another example, a sensor **1528** may comprise a "1 PD per stream" architecture on submount **700** in which each detector **106** comprises four (4) photodiodes **1530**. In sensor **1528**, each individual photodiode **1530** is coupled to a respective transimpedance amplifier **1532**. The output of the amplifiers **1532** may then be aggregated into averaging circuit **1520** to produce a signal.

As noted previously, one skilled in the art will recognize that the photodiodes and detectors may be arranged in different fashions to optimize the detected light. For example, sensor 1534 illustrates an exemplary "4 PD per stream" sensor in which the detectors 106 comprise photodiodes 1536 arranged in a linear fashion. Likewise, sensor 1538 illustrates an exemplary "1 PD per stream" sensor in which the detectors comprise photodiodes 1540 arranged in a linear fashion.

Alternatively, sensor 1542 illustrates an exemplary "4 PD per stream" sensor in which the detectors 106 comprise photodiodes 1544 arranged in a two-dimensional pattern, such as a zig-zag pattern. Sensor 1546 illustrates an exemplary "1 PD per stream" sensor in which the detectors comprise photodiodes 1548 also arranged in a zig-zag pattern.

FIG. 15L illustrates an exemplary architecture for a switched-capacitor-based front-end. As shown, front-end interfaces 108 may be implemented using switched capacitor circuits and any number of front-end interfaces 108 may be implemented. The output of these switched capacitor circuits may then be provided to a digital interface 1000 and signal processor 110. Switched capacitor circuits may be useful in system 100 for their resistor free design and analog averaging properties. In particular, the switched capacitor circuitry provides for analog averaging of the signal that allows for a lower smaller sampling rate (e.g., 2 KHz sampling for analog versus 48 KHz sampling for digital designs) than similar digital designs. In some embodiments, the switched capacitor architecture in front end interfaces 108 may provide a similar or equivalent SNR to other front end designs, such as a sigma delta architecture. In addition, a switched capacitor design in front end interfaces 108 may require less computational power by signal processor 110 to perform the same amount of decimation to obtain the same

FIGS. 16A and 16B illustrate embodiments of disposable optical sensors 1600. In an embodiment, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be incorporated into the disposable sensors 1600 shown. For instance, the sensors 1600 can be used as the sensors 101 in the system 100 described above with respect to FIG. 1. Moreover, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be implemented in other disposable sensor designs that are not depicted herein.

The sensors 1600 include an adult/pediatric sensor 1610 for finger placement and a disposable infant/neonate sensor 1602 configured for toe, foot or hand placement. Each sensor 1600 has a tape end 1610 and an opposite connector end 1620 electrically and mechanically interconnected via a flexible coupling 1630. The tape end 1610 attaches an emitter and detector to a tissue site. Although not shown, the tape end 1610 can also include any of the protrusion, shielding, and/or heat sink features described above. The emitter illuminates the tissue site and the detector generates a sensor signal responsive to the light after tissue absorption, such as absorption by pulsatile arterial blood flow within the tissue site.

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The sensor signal is communicated via the flexible coupling 1630 to the connector end 1620. The connector end 1620 can mate with a cable (not shown) that communicates the sensor signal to a monitor (not shown), such as any of the cables or monitors shown above with respect to FIGS. 2A 5 through 2D. Alternatively, the connector end 1620 can mate directly with the monitor.

FIG. 17 illustrates an exploded view of certain of the components of the sensor 301f described above. A heat sink 1751 and a cable 1781 attach to an emitter shell 1704. The 10 emitter shell attaches to a flap housing 1707. The flap housing 1707 includes a receptacle 1709 to receive a cylindrical housing 1480/1580 (not shown) attached to an emitter submount 1702, which is attached to a circuit board 1719.

A spring 1787 attaches to a detector shell 1706 via pins 15 1783, 1785, which hold the emitter and detector shells 1704, 1706 together. A support structure 1791 attaches to the detector shell 1706, which provides support for a shielding enclosure 1790. A noise shield 1713 attaches to the shielding enclosure 1790. A detector submount 1700 is disposed 20 inside the shielding enclosure 1790. A finger bed 1710 provides a surface for placement of the patient's finger. Finger bed 1710 may comprise a gripping surface or gripping features, which may assist in placing and stabilizing a patient's finger in the sensor. A partially cylindrical protru- 25 sion 1705 may also be disposed in the finger bed 1710. As shown, finger bed 1710 attaches to the noise shield 1703. The noise shield 1703 may be configured to reduce noise, such as from ambient light and electromagnetic noise. For example, the noise shield 1703 may be constructed from 30 materials having an opaque color, such as black or a dark blue, to prevent light piping.

Noise shield 1703 may also comprise a thermistor 1712. The thermistor 1712 may be helpful in measuring the temperature of a patient's finger. For example, the thermistor 35 1712 may be useful in detecting when the patient's finger is reaching an unsafe temperature that is too hot or too cold. In addition, the temperature of the patient's finger may be useful in indicating to the sensor the presence of low perfusion as the temperature drops. In addition, the thermistor 1712 may be useful in detecting a shift in the characteristics of the water spectrum in the patient's finger, which can be temperature dependent.

Moreover, a flex circuit cover 1706 attaches to the pins 1783, 1785. Although not shown, a flex circuit can also be 45 provided that connects the circuit board 1719 with the submount 1700 (or a circuit board to which the submount 1700 is connected). A flex circuit protector 1760 may be provided to provide a barrier or shield to the flex circuit (not shown). In particular, the flex circuit protector 1760 may 50 also prevent any electrostatic discharge to or from the flex circuit. The flex circuit protector 1760 may be constructed from well known materials, such as a plastic or rubber materials.

FIG. 18 shows the results obtained by an exemplary 55 sensor 101 of the present disclosure that was configured for measuring glucose. This sensor 101 was tested using a pure water ex-vivo sample. In particular, ten samples were prepared that ranged from 0-55 mg/dL. Two samples were used as a training set and eight samples were then used as a test population. As shown, embodiments of the sensor 101 were able to obtain at least a standard deviation of 13 mg/dL in the training set and 11 mg/dL in the test population.

FIG. **19** shows the results obtained by an exemplary sensor **101** of the present disclosure that was configured for 65 measuring glucose. This sensor **101** was tested using a turbid ex-vivo sample. In particular, 25 samples of water/glucose/

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Liposyn were prepared that ranged from 0-55 mg/dL. Five samples were used as a training set and 20 samples were then used as a test population. As shown, embodiments of sensor 101 were able to obtain at least a standard deviation of 37 mg/dL in the training set and 32 mg/dL in the test population.

FIGS. 20 through 22 shows other results that can be obtained by an embodiment of system 100. In FIG. 20, 150 blood samples from two diabetic adult volunteers were collected over a 10-day period. Invasive measurements were taken with a YSI glucometer to serve as a reference measurement. Noninvasive measurements were then taken with an embodiment of system 100 that comprised four LEDs and four independent detector streams. As shown, the system 100 obtained a correlation of about 85% and Arms of about 31 mg/dL.

In FIG. 21, 34 blood samples were taken from a diabetic adult volunteer collected over a 2-day period. Invasive measurements were also taken with a glucometer for comparison. Noninvasive measurements were then taken with an embodiment of system 100 that comprised four LEDs in emitter 104 and four independent detector streams from detectors 106. As shown, the system 100 was able to attain a correlation of about 90% and Arms of about 22 mg/dL.

The results shown in FIG. 22 relate to total hemoglobin testing with an exemplary sensor 101 of the present disclosure. In particular, 47 blood samples were collected from nine adult volunteers. Invasive measurements were then taken with a CO-oximeter for comparison. Noninvasive measurements were taken with an embodiment of system 100 that comprised four LEDs in emitter 104 and four independent detector channels from detectors 106. Measurements were averaged over 1 minute. As shown, the testing resulted in a correlation of about 93% and Arms of about 0.8 mg/dL.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

While certain embodiments of the inventions disclosed herein have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions disclosed herein. Indeed, the novel methods and systems described herein can be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein can be made without departing from the spirit of the inventions disclosed herein. The claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of certain of the inventions disclosed herein.

What is claimed is:

- 1. A user-worn physiological measurement device comprising:
  - one or more emitters configured to emit light into tissue of a user:
  - at least four detectors arranged on a substrate;

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a cover comprising a protruding convex surface, wherein the protruding convex surface extends over all of the at least four detectors arranged on the substrate, wherein at least a portion of the protruding convex surface is rigid;

one or more processors configured to:

receive one or more signals from at least one of the at least four detectors, the one or more signals responsive to at least a physiological parameter of the user; and

process the one or more signals to determine measurements of the physiological parameter;

- a network interface configured to communicate with a mobile phone;
- a touch-screen display configured to provide a user inter- 15 face, wherein:
  - the user interface is configured to display indicia responsive to the measurements of the physiological parameter, and
  - an orientation of the user interface is configurable 20 responsive to a user input;
- a wall that surrounds at least the at least four detectors, wherein the wall operably connects to the substrate and the cover:
- a storage device configured to at least temporarily store at 25 least the measurements of the physiological parameter; and
- a strap configured to position the physiological measurement device on the user.
- 2. The user-worn physiological measurement device of 30 claim 1, wherein the protruding convex surface is configured to be located between tissue of the user and the at least four detectors when the physiological measurement device is worn by the user.
- 3. The user-worn physiological measurement device of 35 claim 2, wherein at least part of the protruding convex surface is light permeable to allow light to reach at least one of the at least four detectors.
- **4.** The user-worn physiological measurement device of claim **2**, wherein the at least four detectors are arranged on 40 a first surface of the substrate.
- 5. The user-worn physiological measurement device of claim 4, wherein:

the wall operably connects to the substrate on one side of the wall,

the wall operably connects to the cover on an opposing side of the wall, and

the wall surrounds at least the at least four detectors on the first surface.

- 6. The user-worn physiological measurement device of 50 claim 5, further comprising a single unit wearable by the user, the single unit encompassing the one or more emitters, the at least four detectors, the wall, the cover, the one or more processors, the network interface, and the storage device.
- 7. The user-worn physiological measurement device of claim 6, wherein a surface of the single unit positions the touch-screen display, and wherein the strap is attached to the single unit
- **8**. The user-worn physiological measurement device of 60 claim **7**, wherein the network interface is configured to communicate at least the measurements of the physiological parameter to the mobile phone.
- **9**. The user-worn physiological measurement device of claim **7**, wherein the network interface is further configured 65 to wirelessly communicate with the mobile phone or with a computer network.

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- 10. The user-worn physiological measurement device of claim 7, wherein the physiological parameter comprises at least one of: pulse rate, glucose, oxygen, oxygen saturation, methemoglobin, total hemoglobin, carboxyhemoglobin, or carbon monoxide.
- 11. The user-worn physiological measurement device of claim 10 further comprising:
- a magnet configured to be used as a connecting mechanism.
- 12. The user-worn physiological measurement device of claim 10, wherein the one or more processors are further configured to modulate a duty cycle of one or more of the one or more emitters, and wherein the modulation includes pulse width time slots and off time slots.
- 13. The user-worn physiological measurement device of claim 10, wherein the displayed indicia are further responsive to temperature.
- 14. The user-worn physiological measurement device of claim 10, wherein the physiological parameter comprises a state or trend of wellness of the user.
- 15. The user-worn physiological measurement device of claim 10, wherein a portion of the physiological measurement device comprises one of at least two sizes, the two sizes intended to be appropriate for larger users and smaller users
- 16. The user-worn physiological measurement device of claim 10, wherein the protruding convex surface protrudes a height between 1 millimeter and 3 millimeters.
- 17. The user-worn physiological measurement device of claim 16, wherein the protruding convex surface protrudes a height greater than 2 millimeters and less than 3 millimeters
- 18. The user-worn physiological measurement device of claim 10, wherein each of the at least four detectors has a corresponding window that allows light to pass through to the detector.
- 19. The user-worn physiological measurement device of claim 18 further comprising:
  - an at least partially opaque layer blocking one or more optical paths to at least one of the at least four detectors, wherein the at least partially opaque layer comprises the windows that allow light to pass through to the corresponding detectors.
- 20. The user-worn physiological measurement device of claim 10, wherein the at least four detectors are arranged such that a first detector and a second detector of the at least four detectors are arranged across from each other on opposite sides of a central point along a first axis, and a third detector and a fourth detector of the at least four detectors are arranged across from each other on opposite sides of the central point along a second axis which is different from the first axis.
  - 21. The user-worn physiological measurement device of claim 20, wherein the first axis is perpendicular to the second axis.
  - 22. The user-worn physiological measurement device of claim 20, wherein the first, second, third and fourth detectors form a cross pattern about the central point.
  - 23. The user-worn physiological measurement device of claim 10, wherein the wall creates one or more gaps between the first surface of the substrate and a surface of the cover that is interior to the physiological measurement device, and wherein the at least four detectors are positioned on the first surface of the substrate within the one or more gaps.
  - **24**. The user-worn physiological measurement device of claim **10**, wherein the at least four detectors comprise at least eight detectors.

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- 25. The user-worn physiological measurement device of claim 10, wherein at least one of the detectors is configured to detect light that has been attenuated by tissue of the user.
- **26**. The user-worn physiological measurement device of claim **25**, wherein the attenuated light is reflected by the 5 tissue.
  - 27. A physiological measurement system comprising: the user-worn physiological measurement device according to claim 1; and
  - the mobile phone in communication with the physiologi- 10 cal measurement device.
- **28**. The physiological measurement system of claim **27**, wherein the network interface of the physiological measurement device is configured to wirelessly communicate, and wherein the mobile phone wirelessly communicates with the 15 network interface.
  - 29. A physiological measurement system comprising: the user-worn physiological measurement device according to claim 24; and
  - the mobile phone in communication with the physiologi- 20 cal measurement device.
- **30**. The physiological measurement system of claim **29**, wherein the network interface of the physiological measurement device is configured to wirelessly communicate, and wherein the mobile phone wirelessly communicates with the 25 network interface.

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### (54) MULTI-STREAM DATA COLLECTION SYSTEM FOR NONINVASIVE MEASUREMENT OF BLOOD CONSTITUENTS

(71) Applicant: Masimo Corporation, Irvine, CA (US)

(72) Inventors: Jeroen Poeze, Rancho Santa Margarita,
CA (US); Marcelo Lamego, Cupertino,
CA (US); Sean Merritt, Lake Forest,
CA (US); Cristiano Dalvi, Lake Forest,
CA (US); Hung Vo, Fountain Valley,
CA (US); Johannes Bruinsma,
Opeinde (NL); Ferdyan Lesmana,
Irvine, CA (US); Massi Joe E. Kiani,
Laguna Niguel, CA (US); Greg Olsen,

Lake Forest, CA (US)

(73) Assignee: Masimo Corporation, Irvine, CA (US)

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### (56) References Cited

### U.S. PATENT DOCUMENTS

3,910,701 A 10/1975 Henderson et al. 4,114,604 A 9/1978 Shaw et al. (Continued)

#### FOREIGN PATENT DOCUMENTS

CN 1270793 A 10/2000 CN 101564290 B 10/2009 (Continued)

### OTHER PUBLICATIONS

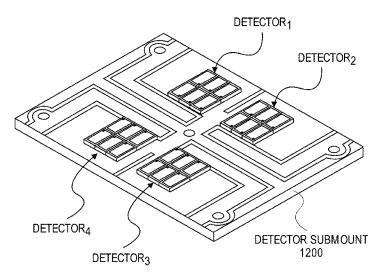
US 8,845,543 B2, 09/2014, Diab et al. (withdrawn) (Continued)

Primary Examiner — Eric F Winakur Assistant Examiner — Chu Chuan Liu (74) Attorney, Agent, or Firm — Knobbe Martens Olson & Bear LLP

### (57) ABSTRACT

The present disclosure relates to noninvasive methods, devices, and systems for measuring various blood constituents or analytes, such as glucose. In an embodiment, a light source comprises LEDs and super-luminescent LEDs. The light source emits light at at least wavelengths of about 1610 nm, about 1640 nm, and about 1665 nm. In an embodiment, the detector comprises a plurality of photodetectors arranged in a special geometry comprising one of a substantially linear substantially equal spaced geometry, a substantially linear substantially non-equal spaced geometry, and a substantially grid geometry.

### 30 Claims, 65 Drawing Sheets



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### Related U.S. Application Data

continuation of application No. 16/534,949, filed on Aug. 7, 2019, now Pat. No. 10,588,553, which is a continuation of application No. 16/409,515, filed on May 10, 2019, now Pat. No. 10,376,191, which is a continuation of application No. 16/261,326, filed on Jan. 29, 2019, now Pat. No. 10,292,628, which is a continuation of application No. 16/212,537, filed on Dec. 6, 2018, now Pat. No. 10,258,266, which is a continuation of application No. 14/981,290, filed on Dec. 28, 2015, now Pat. No. 10,335,068, which is a continuation of application No. 12/829,352, filed on Jul. 1, 2010, now Pat. No. 9,277,880, which is a continuation of application No. 12/534,827, filed on Aug. 3, 2009, now abandoned, and a continuationin-part of application No. 12/497,528, filed on Jul. 2, 2009, now Pat. No. 8,577,431, which is a continuation-in-part of application No. 29/323,408, filed on Aug. 25, 2008, now Pat. No. Des. 606,659, and a continuation-in-part of application No. 29/323,409, filed on Aug. 25, 2008, now Pat. No. Des. 621,516, said application No. 12/829,352 is a continuation-inpart of application No. 12/497,523, filed on Jul. 2, 2009, now Pat. No. 8,437,825, which is a continuation-in-part of application No. 29/323,408, filed on Aug. 25, 2008, now Pat. No. Des. 606,659, and a continuation-in-part of application No. 29/323,409, filed on Aug. 25, 2008, now Pat. No. Des. 621,516.

(60) Provisional application No. 61/086,060, filed on Aug. 4, 2008, provisional application No. 61/086,108, filed on Aug. 4, 2008, provisional application No. 61/086,063, filed on Aug. 4, 2008, provisional application No. 61/086,057, filed on Aug. 4, 2008, provisional application No. 61/091,732, filed on Aug. 25, 2008, provisional application No. 61/078,228, filed on Jul. 3, 2008, provisional application No. 61/078,207, filed on Jul. 3, 2008.

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See application file for complete search history.

### (56) References Cited

#### U.S. PATENT DOCUMENTS

4,258,719 A	3/1981	Lewyn
4,267,844 A	5/1981	Yamanishi
4,438,338 A	3/1984	Stitt
4,444,471 A	4/1984	Ford et al.
4,653,498 A	3/1987	New, Jr. et al.
4,655,225 A	4/1987	Dahne et al.
4,684,245 A	8/1987	Goldring
4,709,413 A	11/1987	Forrest
4,755,676 A	7/1988	Gaalema et al.
4,781,195 A	11/1988	Martin
4.805.623 A	2/1989	Jöbsis

4,825,872 A	A 5/1989	Tan et al.
4,880,304 A		Jaeb et al.
		Gordon et al.
4,964,408 A		Hink et al.
5,028,787 A	A 7/1991	Rosenthal et al.
5,035,243 A	A 7/1991	Muz
5,041,187		Hink et al.
5,043,820 A		Wyles et al.
5,069,213 A	A 12/1991	Polczynski
5,069,214 A	A 12/1991	Samaras et al.
5,077,476 A		Rosenthal
5,086,229 A		Rosenthal et al.
5,099,842 A		Mannheimer et al.
D326,715 S	6/1992	Schmidt
5,122,925	A 6/1992	Inpyn
5,131,391 A		Sakai et al.
5,137,023 A		Mendelson et al.
5,158,091 A	A 10/1992	Butterfiled et al.
5,159,929 A	A 11/1992	McMillen et al.
5,163,438 A		Gordon et al.
5,203,329 A		Takatani et al.
5,222,295 A	A 6/1993	Dorris, Jr.
5,222,495 A	A 6/1993	Clarke et al.
5,222,496 A		Clarke et al.
5,228,449 A		Christ et al.
5,249,576 A	A 10/1993	Goldberger et al.
5,250,342 A	10/1993	Lang
5,278,627 A		Aoyagi et al.
5,297,548 A		Pologe
5,319,355 A	A 6/1994	Russek
5,333,616 A	A 8/1994	Mills et al.
5,337,744 A	8/1994	Branigan
5,337,745 A		Benaron
5,341,805 A		Stavridi et al.
5,355,242 A	10/1994	Eastmond et al.
5,358,519 A	A 10/1994	Grandjean
5,362,966 A		Rosenthal et al.
D353,195 S		Savage et al.
D353,196 S	3 12/1994	Savage et al.
5,377,676 A	1/1995	Vari et al.
D356,870 S	3/1995	Ivers et al.
		Savage et al.
5,427,093 A		Ogawa et al.
5,431,170 A	A 7/1995	Mathews
D361,840 S		Savage et al.
5,437,275 A		Amundsen et al.
5,441,054 A		Tsuchiya
D362,063 S	9/1995	Savage et al.
5,452,717 A	A 9/1995	Branigan et al.
D363,120 S		Savage et al.
		~ .
5,456,252 A		Vari et al.
5,462,051 A	A 10/1995	Oka et al.
5,479,934 A	A 1/1996	Imran
5,482,034		Lewis et al.
		Diab et al.
5,482,036 A		
5,490,505 A		Diab et al.
5,490,506 A	A 2/1996	Takatani et al.
5,490,523 A	A 2/1996	Isaacson et al.
5,494,043 A		O'Sullivan et al.
		Rosenheimer
5,511,546 A		Hon
5,533,511 A	A 7/1996	Kaspari et al.
5,534,851 A	A 7/1996	Russek
5,551,422 A		Simonsen et al.
5,553,615 A		Carim et al.
5,553,616 A	A 9/1996	Ham et al.
5,561,275 A	10/1996	Savage et al.
5,562,002 A		Lalin
5,564,429 A		Bornn et al.
5,584,296 A	A 12/1996	Cui et al.
5,590,649	A 1/1997	Caro et al.
5,601,079 A		Wong et al.
5,602,924 A		Durand et al.
D378,414 S	3/1997	Allen et al.
5,623,925 A	4/1997	Swenson et al.
, ,		
, ,		Alfano et al.
5,632,272 A		Diab et al.
5,638,816 A	A 6/1997	Kiani-Azarbayjany et al.
5,638,818 A		Diab et al.
2,020,010 F	a 0/199/	Diau Gi al.

Case: 22-1972 Document: 33-2 Page: 113 Filed: 05/11/2023

(56)		Referen	ces Cited	6,241,680		6/2001	
	HS	PATENT	DOCUMENTS	6,241,683 6,241,684			Macklem et al. Amano et al.
	0.5.	IMILINI	DOCOMENTS	6,253,097	B1	6/2001	Aronow et al.
5,645,44			Tobler et al.	6,256,523 6,263,222			Diab et al. Diab et al.
5,676,14 5,685,29			Simonsen et al. Diab et al.	6,278,522			Lepper, Jr. et al.
5,687,7	17 A	11/1997	Halpern et al.	6,278,889			Robinson
5,699,80 D390,66		12/1997	John Lagerlof	6,280,213 6,285,896		8/2001 9/2001	Tobler et al. Tobler et al.
5,729,20			Oka et al.	6,297,969	B1	10/2001	Mottahed
D393,83			Tobler et al.	6,301,493 6,308,089			Marro et al. von der Ruhr et al.
5,743,26 5,750,92			Lepper, Jr. et al. Baltazar	6,317,627			Ennen et al.
5,752,9	14 A	5/1998	Delonzor et al.	6,321,100 D452,012		11/2001 12/2001	
5,758,64 5,760,91			Diab et al. Lepper, Jr. et al.	6,325,761		12/2001	Jay
5,766,13		6/1998	Kondo et al.	6,334,065			Al-Ali et al.
5,769,78 5,782,7			Diab et al. Diab et al.	6,343,223 6,343,224		1/2002	Chin et al. Parker
5,785,65			Caro et al.	6,345,194	В1	2/2002	Nelson et al.
5,791,34			Flaherty et al.	6,349,228 6,353,750			Kiani et al. Kimura et al.
5,792,0: 5,795,30		8/1998 8/1998	Isaacson et al. Bryars	6,356,203		3/2002	Halleck et al.
5,800,34	49 A	9/1998	Isaacson et al.	6,360,113 6,360,114			Dettling Diab et al.
5,807,24 5,810,73			Merchant et al. Caro et al.	6,360,115			Greenwald et al.
5,823,9			Diab et al.	D455,834	S		Donars et al.
5,826,88			Helgeland	6,368,283 6,371,921			Xu et al. Caro et al.
5,830,13 5,830,13		11/1998	Caro et al. Scharf	6,377,829	B1	4/2002	Al-Ali
5,833,6	18 A		Caro et al.	6,388,240 6,397,091			Schulz et al. Diab et al.
D403,0′ 5,851,1′		12/1998	Maeda et al. Aronow	6,430,437		8/2002	
5,860,9	19 A	1/1999	Kiani-Azarbayjany et al.	6,430,525			Weber et al.
5,890,92 5,902,23			Mills et al. Lewis et al.	D463,561 6,463,187			Fukatsu et al. Baruch et al.
5,903,3		5/1999		6,463,311	B1	10/2002	Diab
5,904,63			Wohltmann et al.	6,470,199 6,470,893		10/2002 10/2002	Kopotic et al.
5,919,13 5,934,92		7/1999 8/1999	Tobler et al.	6,475,153	B1	11/2002	Khair et al.
5,940,18	32 A	8/1999	Lepper, Jr. et al.	RE37,922		12/2002	Sharan Bridger et al.
5,957,8 <sup>2</sup> D414,8′			Terasawa et al. Saltzstein et al.	6,491,647 6,501,975			Diab et al.
5,987,34	43 A	11/1999	Kinast	6,505,059			Kollias et al.
5,995,85 5,997,34			Kiani et al. Mills et al.	6,515,273 6,516,289		2/2003 2/2003	David et al.
6,002,9:			Diab et al.	6,519,487	B1	2/2003	Parker
6,011,98			Diab et al.	6,522,521 6,525,386			Mizuno et al. Mills et al.
6,018,6′ 6,027,4:			Chin et al. Flaherty et al.	6,526,300		2/2003	
6,036,64	42 A	3/2000	Diab et al.	6,541,756 6,542,764		4/2003	Schulz et al. Al-Ali et al.
6,045,50 6,049,72			Caro et al. Crothall	6,556,852			Schulze et al.
6,067,40	52 A	5/2000	Diab et al.	6,580,086			Schulz et al.
6,081,73 6,088,60			Diab et al. Diab et al.	6,584,336 6,595,316			Ali et al. Cybulski et al.
6,102,85	56 A		Groff et al.	6,597,932	B2	7/2003	Tian et al.
6,110,52			Lepper, Jr. et al.	6,597,933 6,606,509	B2 B2		Kiani et al. Schmitt
6,124,59 6,128,52			Shehada Marro et al.	6,606,511	B1	8/2003	Ali et al.
6,129,6		10/2000		D481,459 6,632,181		10/2003	Nahm Flaherty et al.
6,144,86 6,144,86		11/2000	Miesel et al. Parker	6,636,759		10/2003	Robinson
6,151,5	16 A	11/2000	Kiani-Azarbayjany et al.	6,639,668 6,639,867		10/2003 10/2003	Trepagnier
6,152,73 6,157,83			Gerhardt et al. Diab et al.	6,640,116		10/2003	
6,165,00	05 A	12/2000	Mills et al.	6,643,530			Diab et al.
6,167,25 6,172,74			Schmidt et al. Kley et al.	6,650,917 6,650,939			Diab et al. Takpke, II et al.
6,172,72			Say et al.	6,654,624	B2	11/2003	Diab et al.
6,181,9	58 B1	1/2001	Steuer et al.	6,658,276			Kiani et al.
6,184,52 6,202,93		3/2001	Coffin, IV et al. Plesko	6,661,161 6,668,185		12/2003	Lanzo et al. Toida
6,206,83	30 B1	3/2001	Diab et al.	6,671,526	B1	12/2003	Aoyagi et al.
6,223,06			Chaiken et al.	6,671,531			Al-Ali et al.
6,229,83 6,232,60		5/2001	Diab et al. Snyder et al.	6,678,543 6,681,133			Diab et al. Chaiken et al.
6,236,8			Diab et al.	6,684,090			Ali et al.

(56)	Referen	ces Cited	7,149,561 B2	12/2006	
11.9	PATENT	DOCUMENTS	D535,031 S D537,164 S	2/2007	Barrett et al. Shigemori et al.
0	), 17X1L1V1	BOCOMENTS	7,186,966 B2	3/2007	
6,684,091 B2	1/2004	Parker	7,190,261 B2	3/2007	
6,697,656 B1		Al-Ali	7,215,984 B2	5/2007 5/2007	
6,697,657 B1		Shehada et al.	7,215,986 B2 7,221,971 B2	5/2007	
6,697,658 B2 RE38,476 E		Diab et al.	7,225,006 B2		Al-Ali et al.
6,699,194 B1		Diab et al.	7,225,007 B2		Al-Ali
6,714,804 B2		Al-Ali et al.	RE39,672 E		Shehada et al.
RE38,492 E		Diab et al.	7,227,156 B2 7,230,227 B2		Colvin, Jr. et al. Wilcken et al.
6,721,582 B2 6,721,585 B1		Trepagnier et al. Parker	D547,454 S	7/2007	
6,725,075 B2			7,239,905 B2		Kiani-Azarbayjany et al.
6,728,560 B2		Kollias et al.	7,245,953 B1	7/2007	
6,735,459 B2		Parker	D549,830 S 7,254,429 B2		Behar et al. Schurman et al.
6,745,060 B2 6,748,254 B2		Diab et al. O'Neil et al.	7,254,431 B2	8/2007	
6,760,607 B2		Al-Ali	7,254,433 B2		Diab et al.
6,770,028 B1	8/2004	Ali et al.	7,254,434 B2		Schulz et al.
6,771,994 B2		Kiani et al.	D550,364 S D551,350 S		Glover et al. Lorimer et al.
6,785,568 B2 6,792,300 B1		Chance Diab et al.	7,272,425 B2	9/2007	
6,801,799 B2		Mendelson	7,274,955 B2		Kiani et al.
6,811,535 B2	11/2004	Palti et al.	D553,248 S	10/2007	
6,813,511 B2		Diab et al.	D554,263 S 7,280,858 B2	10/2007	Al-Ali et al.
6,816,010 B2 6,816,241 B2		Seetharaman et al. Grubisic et al.	7,289,835 B2		Mansfield et al.
6,816,741 B2			7,292,883 B2		De Felice et al.
6,822,564 B2	11/2004	Al-Ali	7,295,866 B2	11/2007	
6,826,419 B2		Diab et al.	D562,985 S 7,328,053 B1		Brefka et al. Diab et al.
6,830,711 B2 6,831,266 B2		Mills et al. Paritsky et al.	7,332,784 B2		Mills et al.
6,850,787 B2		Weber et al.	7,340,287 B2		Mason et al.
6,850,788 B2		Al-Ali	7,341,559 B2		Schulz et al.
6,852,083 B2		Caro et al.	7,343,186 B2 D566,282 S		Lamego et al. Al-Ali et al.
D502,655 S 6,861,639 B2		Huang	D567,125 S		Okabe et al.
6,897,788 B2		Khair et al.	7,355,512 B1	4/2008	Al-Ali
6,898,452 B2		Al-Ali et al.	7,356,365 B2		Schurman
6,912,413 B2		Rantala et al.	7,365,923 B2 D569,001 S	4/2008 5/2008	Hargis et al.
6,920,345 B2 D508,862 S		Al-Ali et al. Behar et al.	D569,521 S	5/2008	
6,931,268 B1		Kiani-Azarbayjany et al.	7,371,981 B2		Abdul-Hafiz
6,934,570 B2	8/2005	Kiani et al.	7,373,193 B2		Al-Ali et al.
6,939,305 B2		Flaherty et al.	7,373,194 B2 7,376,453 B1		Weber et al. Diab et al.
6,943,348 B1 6,950,687 B2		Coffin, IV	7,377,794 B2		Al Ali et al.
D510,625 S		Widener et al.	7,377,899 B2	5/2008	Weber et al.
6,961,598 B2	11/2005	Diab	7,383,070 B2		Diab et al.
6,970,792 B1			7,395,189 B2 7,415,297 B2	7/2008 8/2008	Qing et al. Al-Ali et al.
6,979,812 B2 6,985,764 B2		Al-Ali Mason et al.	7,428,432 B2		Ali et al.
6,993,371 B2		Kiani et al.	7,438,683 B2	10/2008	Al-Ali et al.
D514,461 S	2/2006		7,440,787 B2	10/2008	
6,995,400 B2		Mizuyoshi	7,454,240 B2 7,467,002 B2		Diab et al. Weber et al.
6,996,427 B2 6,999,904 B2		Ali et al. Weber et al.	7,469,157 B2		Diab et al.
7,003,338 B2		Weber et al.	7,471,969 B2		Diab et al.
7,003,339 B2		Diab et al.	7,471,971 B2 7,483,729 B2		Diab et al.
7,015,451 B2 7,024,233 B2		Dalke et al.	7,483,730 B2		Al-Ali et al. Diab et al.
7,024,233 B2 7,026,619 B2		Ali et al. Cranford	7,489,958 B2		Diab et al.
7,027,849 B2		Al-Ali	7,496,391 B2		Diab et al.
7,030,749 B2		Al-Ali	7,496,393 B2 D587.657 S		Diab et al. Al-Ali et al.
7,039,449 B2 7,041,060 B2		Al-Ali Flaherty et al.	7,499,741 B2		Diab et al.
7,041,000 B2 7,044,918 B2			7,499,835 B2		Weber et al.
7,047,054 B2	5/2006	Benni	7,500,950 B2		Al-Ali et al.
7,048,687 B1		Reuss et al.	7,509,153 B2		Blank et al.
7,060,963 B2 7,067,893 B2		Maegawa et al. Mills et al.	7,509,154 B2 7,509,494 B2	3/2009 3/2009	Diab et al.
7,007,893 B2 7,092,757 B2		Larson et al.	7,510,849 B2		Schurman et al.
7,096,052 B2		Mason et al.	7,519,327 B2	4/2009	
7,096,054 B2	8/2006	Abdul-Hafiz et al.	7,526,328 B2	4/2009	Diab et al.
7,113,815 B2		O'Neil et al.	7,530,942 B1	5/2009	
7,132,641 B2		Schulz et al. Kiani et al.	7,530,949 B2 7,530,955 B2		Al Ali et al. Diab et al.
7,142,901 B2	11/2006	Kiani et al.	1,330,933 <b>B</b> 2	3/2009	Diau et al.

(56)		Referen	ces Cited		935 B2		Besko et al.
	U.S. I	PATENT	DOCUMENTS		620 B2	2/2012 2/2012	Al-Ali et al.
7.562.11	0. D2	7/2000			528 B2 531 B2		Diab et al. Crowley
7,563,11 7,596,39			Al-Ali et al. Al-Ali et al.	8,128,	572 B2	3/2012	Diab et al.
7,601,12	3 B2		Tweed et al.		105 B2 287 B2		Al-Ali et al. Diab et al.
7,606,60 D603,96			Laakkonen Jones et al.		487 B2		Diab et al.
7,613,49	0 B2	11/2009	Sarussi et al.		672 B2	5/2012	
7,618,37 D606,65		11/2009	Flaherty Kiani et al.		420 B2 443 B1	5/2012	Diab et al. Kiani
7,647,08	3 B2	1/2010	Al-Ali et al.		180 B2		Diab et al.
D609,19 7,657,29			Al-Ali et al. Eghbal et al.		223 B2 227 B2		Al-Ali et al. Diab et al.
7,657,29		2/2010	Coakley et al.	8,203,	438 B2		Kiani et al.
7,657,29 D614,30			Raridan et al. Al-Ali et al.		704 B2 566 B2		Merritt et al. Schurman et al.
RE41,31		5/2010		8,219,	170 B2	7/2012	Hausmann et al.
7,726,20 7,729,73			Ruotoistenmaki Al-Ali et al.		172 B2 411 B2		Schurman et al. Al-Ali et al.
7,734,32		6/2010		8,228,	181 B2	7/2012	Al-Ali
7,740,58		6/2010			532 B2 533 B2	7/2012 7/2012	Davis Diab et al.
7,740,58 7,761,12			Maschke et al. Al-Ali et al.	8,233,	955 B2	7/2012	Al-Ali et al.
7,761,12	8 B2	7/2010	Al-Ali et al.		325 B2 326 B2		Al-Ali et al. Ninomiya et al.
7,764,98 D621,51			Dalke et al. Kiani et al.		026 B1	8/2012	
7,791,15	5 B2	9/2010	Diab		027 B2		Al-Ali et al. Al-Ali et al.
7,801,58 7,809,41		9/2010 10/2010			028 B2 577 B2		Weber et al.
7,822,45	2 B2	10/2010	Schurman et al.	8,265,	723 B1	9/2012	McHale et al.
RE41,91 7,844,31		11/2010	Parker Kiani et al.		360 B2 473 B2	9/2012 10/2012	Sampath et al. Al-Ali
7,844,31		11/2010		8,289,	130 B2	10/2012	Nakajima et al.
7,844,31		11/2010	Al-Ali Ruotoistenmaki		217 B2 596 B2		Al-Ali et al. Schurman et al.
7,862,52 7,865,22			Weber et al.	8,310,	336 B2	11/2012	Muhsin et al.
7,869,84			Ollerdessen et al.	8,315, RE43,	683 B2 860 F	11/2012 12/2012	Al-Ali et al. Parker
7,873,49 7,880,60		2/2011	Weber et al. Al-Ali	8,280,	469 B2	12/2012	Baker, Jr.
7,880,62	6 B2	2/2011	Al-Ali et al.		006 B2 403 B2		Naganuma et al. Al-Ali et al.
7,884,31 7,891,35			Hamada Al-Ali et al.		330 B2		Lamego
7,894,86	8 B2	2/2011	Al-Ali et al.		842 B2 766 B2		Al-Ali et al. MacNeish, III et al.
7,899,50 7,899,50			Xu et al. Al-Ali et al.		080 B2		Diab et al.
7,899,51	0 B2	3/2011	Hoarau		223 B2 226 B2		Al-Ali et al.
7,899,51 7,904,13		3/2011 3/2011	Trepagnier et al. Weber et al.		389 B2		Diab et al. Dorogusker et al.
7,909,77	2 B2	3/2011	Popov et al.	8,374,	665 B2	2/2013	Lamego
7,910,87		3/2011			272 B2 995 B2		Barrett et al. Al-Ali et al.
7,919,71 7,937,12		5/2011	Al-Ali et al. Al-Ali	8,385,	996 B2	2/2013	Smith et al.
7,937,12 7,937,13			Mason et al. Diab et al.		353 B2 822 B2	3/2013 3/2013	Kiani et al. Al-Ali
7,937,13 7,941,19		5/2011		8,401,	602 B2	3/2013	Kiani
7,951,08			Flaherty et al.		608 B2 499 B2		Al-Ali et al. Al-Ali et al.
7,957,78 7,962,18			Lamego et al. Kiani et al.	8,418,	524 B2	4/2013	Al-Ali
7,962,19		6/2011	Diab et al.		022 B2 106 B2		Rozenfeld Lamego et al.
7,976,47 7,988,63		7/2011 8/2011			674 B2	4/2013	Duffy et al.
7,990,38	2 B2	8/2011	Kiani		967 B2 817 B1	4/2013	Olsen et al. Al-Ali et al.
7,991,44 8,000,76		8/2011 8/2011	Ali et al. Al-Ali	8,437,	825 B2		Dalvi et al.
8,008,08	8 B2	8/2011	Bellott et al.	8,452,	364 B2 290 B2		Hannula et al.
RE42,75 8,019,40			Kiani-Azarbayjany et al. Diab et al.		703 B2	6/2013	Siskavich Al-Ali
8,028,70	1 B2	10/2011	Al-Ali et al.	8,457,	707 B2	6/2013	Kiani
8,029,76 8,036,72			Bellott et al. Schurman et al.		349 B2 286 B2		Diab et al. Bellot et al.
8,036,72			Diab et al.	8,471,	713 B2	6/2013	Poeze et al.
8,044,99		10/2011			020 B2		Kiani et al.
8,046,04 8,046,04			Ali et al. Diab et al.		787 B2 364 B2		Al-Ali et al. Weber et al.
8,046,04	2 B2	10/2011	Diab et al.	8,496,	595 B2	7/2013	Jornod
8,048,04		11/2011			684 B2		Weber et al.
8,050,72	о B2	11/2011	Al-Ali et al.	8,504,	128 B2	8/2013	Blank et al.

Case: 22-1972 Document: 33-2 Page: 116 Filed: 05/11/2023

(56)		Referen	ces Cited	8,801,613 E		Al-Ali et al.
	U.S.	PATENT	DOCUMENTS	8,821,397 E 8,821,415 E		Al-Ali et al. Al-Ali et al.
	0.0.		DOCOMENTO	8,830,449 E	9/2014	Lamego et al.
8,509,8			Workman et al.	8,831,700 E 8,838,210 E		Schurman et al. Wood et al.
8,515,5 8,515,5			Bruinsma et al. McKenna et al.	8,840,549 E		Al-Ali et al.
8,523,7		9/2013		8,847,740 B	9/2014	Kiani et al.
8,529,3			Al-Ali et al.	8,849,365 E		Smith et al.
8,532,7			Ali et al.	8,852,094 E 8,852,994 E		Al-Ali et al. Wojtczuk et al.
8,532,7 D692,1			Diab et al. Al-Ali et al.	8,868,147 E	2 10/2014	Stippick et al.
8,547,2	09 B2	10/2013	Kiani et al.	8,868,150 E		Al-Ali et al.
8,548,5		10/2013	Al-Ali Schurman et al.	8,870,792 E 8,886,271 E		Al-Ali et al. Kiani et al.
8,548,5 8,548,5			Al-Ali et al.	8,888,539 E		Al-Ali et al.
8,560,0	32 B2	10/2013	Al-Ali et al.	8,888,708 E		Diab et al.
8,560,0			Diab et al.	8,892,180 E 8,897,847 E		Weber et al.
8,570,1 8,570,5		10/2013 10/2013		8,909,310 E		Lamego et al.
8,571,6	17 B2	10/2013	Reichgott et al.	8,911,377 E		
8,571,6			Lamego et al.	8,912,909 E 8,920,317 E		Al-Ali et al. Al-Ali et al.
8,571,6 8,577,4			Al-Ali et al. Lamego et al.	8,920,332 E		Hong et al.
8,581,7	32 B2	11/2013	Al-Ali et al.	8,921,699 E		Al-Ali et al.
8,584,3			Al-Ali et al.	8,922,382 E 8,929,964 E		Al-Ali et al. Al-Ali et al.
8,588,8 8,591,4			Abdul-Hafiz et al. Onoe et al.	8,942,777 B		Diab et al.
8,600,4	67 B2		Al-Ali et al.	8,948,834 E		Diab et al.
8,602,9		12/2013		8,948,835 E 8,965,471 E		Lamego
8,606,3 8,615,2	42 B2 90 B2	12/2013 12/2013	Lin et al.	8,983,564 E		
8,626,2	55 B2		Al-Ali et al.	8,989,831 E		Al-Ali et al.
8,630,6			Lamego et al.	8,996,085 E 8,998,809 E		Kiani et al. Kiani
8,634,8 8,641,6			Al-Ali et al. Sierra et al.	9,028,429 E		Telfort et al.
8,652,0	60 B2	2/2014		9,037,207 E		Al-Ali et al.
8,655,0			Prest et al.	9,060,721 E 9,066,666 E		Reichgott et al. Kiani
8,663,1 8,666,4		3/2014 3/2014		9,066,680 E		Al-Ali et al.
8,667,9	67 B2	3/2014	Al-Ali et al.	9,072,437 E		Paalasmaa
8,670,8			O'Reilly Diab et al.	9,072,474 B 9,078,560 B		Al-Ali et al. Schurman et al.
8,670,8 8,676,2			Weber et al.	9,081,889 E	7/2015	Ingrassia, Jr. et al.
8,682,4	07 B2	3/2014	Al-Ali	9,084,569 E		Weber et al. Welch et al.
RE44,8		4/2014	Parker Kiani et al.	9,095,316 E 9,106,038 E		Telfort et al.
RE44,8 8,688,1			Bruinsma et al.	9,107,625 E		Telfort et al.
8,690,7	99 B2	4/2014	Telfort et al.	9,107,626 E		Al-Ali et al.
8,700,1		4/2014 4/2014	LeBoeuf et al.	9,113,831 E 9,113,832 E		
8,700,1 8,702,6			Telfort et al.	9,119,595 E	9/2015	Lamego
8,706,1	79 B2	4/2014	Parker	9,131,881 E		Diab et al.
8,712,4 8,715,2			MacNeish, III et al. Telfort et al.	9,131,882 E 9,131,883 E		Al-Ali et al. Al-Ali
8,718,7			Lamego et al.	9,131,917 E	9/2015	Telfort et al.
8,718,7	37 B2	5/2014	Diab et al.	9,138,180 E 9,138,182 E		Coverston et al. Al-Ali et al.
8,718,7 8,720,2		5/2014 5/2014	Blank et al.	9,138,192 E		Weber et al.
8,721,5			Al-Ali et al.	9,142,117 B	9/2015	Muhsin et al.
8,721,5			Al-Ali et al.	9,153,112 E 9,153,121 E		Kiani et al. Kiani et al.
8,723,6 8,740,7		5/2014 6/2014	Kiani et al.	9,161,696 E		Al-Ali et al.
8,754,7			Poeze et al.	9,161,713 B	10/2015	Al-Ali et al.
8,755,5			Telfort et al.	9,167,995 E 9,176,141 E		Lamego et al. Al-Ali et al.
8,755,8 8,755,8			Diab et al. Marinow	9,176,141 E		Bruinsma et al.
8,760,5			Sarwar et al.	9,192,312 B	11/2015	Al-Ali
8,761,8			Lamego	9,192,329 E 9,192,351 E		Al-Ali Telfort et al.
8,764,6 8,768,4		7/2014 7/2014	Kıanı Shakespeare et al.	9,192,331 E		Al-Ali et al.
8,768,4			Haisley et al.	9,210,566 B	12/2015	Ziemianska et al.
8,771,2			Telfort et al.	9,211,072 E		
8,777,6 8,781,5			Kiani et al. Diab et al.	9,211,095 E 9,218,454 E		Al-Alı Kiani et al.
8,781,5			Al-Ali et al.	9,226,696 E		
8,781,5	49 B2	7/2014	Al-Ali et al.	9,241,662 B	1/2016	Al-Ali et al.
8,788,0			Schurman et al.	9,245,668 E		Vo et al.
8,790,2	08 B2	7/2014	AI-AII	9,259,185 B	2/2016	Abdul-Hafiz et al.

(56)		Referen	ces Cited	9,717,45			Lamego et al.
	U.S.	PATENT	DOCUMENTS	9,723,99 9,724,01			Lamego Al-Ali et al.
	0.0			9,724,02		8/2017	
	,572 B2 ,880 B2		Barker et al. Poeze et al.	9,724,02 9,730,64			Kiani et al. Diab et al.
	,880 B2 ,167 B2		Diab et al.	9,743,88			Al-Ali et al.
9,295	,421 B2	3/2016	Kiani et al.	9,749,23			Sampath et al.
	,928 B1		Al-Ali et al.	9,750,44 9,750,44		9/2017 9/2017	Smith et al.
	,382 B2 ,894 B2	4/2016	Varoglu et al. Kiani	9,750,46		9/2017	
D755	,392 S	5/2016	Hwang et al.	9,752,92			Chu et al.
,	,712 B1 ,316 B2	5/2016 5/2016		9,775,54 9,775,54			Al-Ali et al. Diab et al.
	,220 B2		Lamego et al.	9,775,57	0 B2	10/2017	Al-Ali
	,236 B2		Frix et al.	9,778,07 9,781,98			Al-Ali et al. Baranski et al.
	,565 B2 ,673 B2		Lamego et al. Diab et al.	9,782,07			Lamego et al.
	,675 B2		Al-Ali et al.	9,782,11	0 B2	10/2017	Kiani
	,665 B2		Myers et al.	9,787,56 9,788,73		10/2017 10/2017	Lamego et al.
	,181 B2 ,671 B2		Kiani et al. Wojtczuk et al.	9,788,76			Al-Ali et al.
	,325 B2		Al-Ali et al.	9,795,30		10/2017	
	,326 B2		McHale et al.	9,795,31 9,795,35		10/2017	Al-Ali Telfort et al.
	,335 B2 ,185 B2		Al-Ali et al. Ali et al.	9,795,73			Al-Ali et al.
9,386	,953 B2	7/2016	Al-Ali	9,801,55		10/2017	
	,961 B2 ,945 B2		Al-Ali et al. Al-Ali et al.	9,801,58 9,808,18			Weber et al. Perea et al.
	,943 B2 ,448 B2		Al-Ali et al.	9,814,41	8 B2	11/2017	Weber et al.
9,408	,542 B1	8/2016	Kinast et al.	9,820,69 9,833,15		11/2017	Kiani Kiani et al.
	,645 B2 ,759 B1		Al-Ali et al. Lamego et al.	9,833,18			Shakespeare et al.
	,919 B2		Kiani et al.	9,838,77			Qian et al.
	,474 B2		Lamego et al.	9,839,37 9,839,38			Al-Ali et al. Weber et al.
	,422 B2 ,435 B2	11/2016 11/2016		9,847,00			Kiani et al.
9,489	,081 B2	11/2016	Anzures et al.	9,847,74			Kiani et al.
	,110 B2 ,534 B2		Al-Ali et al. Prest et al.	9,848,80 9,848,80			Lee et al. Al-Ali et al.
	,779 B2		Poeze et al.	9,848,80	7 B2	12/2017	Lamego
	,024 B2		Kiani et al.	9,848,82 9,861,29			Raghuram et al. Eckerbom et al.
	,430 B2 ,722 B2		Srinivas et al. Lamego et al.	9,861,30			Al-Ali et al.
9,538	,949 B2	1/2017	Al-Ali et al.	9,861,30			Weber et al.
9,538	,980 B2 ,696 B2		Telfort et al. Lamego et al.	9,866,67 9,867,57			Thompson et al. Maani et al.
9,549	,625 B2		Hatanaka et al.	9,867,57	'8 B2	1/2018	Al-Ali et al.
9,554	,737 B2		Schurman et al.	9,872,62 9,876,32		1/2018	Al-Ali Coverston et al.
	,996 B2 ,998 B2	2/2017 2/2017	Al-Ali et al.	9,870,52			Muhsin et al.
	,019 B2		Al-Ali et al.	9,877,68			Al-Ali et al.
	,039 B2	2/2017	Jansen et al. Dalvi et al.	9,891,07 9,891,59		2/2018 2/2018	Shim et al.
	,975 B2 ,969 B2	3/2017	King	9,895,10			Al-Ali et al.
9,622	,692 B2	4/2017	Lamego et al.	9,898,04 9,913,61			Myers et al. Al-Ali et al.
	,693 B2 ,312 S	4/2017 5/2017	Diab Al-Ali et al.	9,913,61			Singh Alvarado et al.
	,055 B2		Al-Ali et al.	9,924,89			Schurman et al.
	,056 B2	5/2017		9,924,89 9,936,91			Abdul-Hafiz Poeze et al.
	,054 B2 ,405 B1		Lamego et al. Gowreesunker et al.	9,943,26			Muhsin et al.
9,662	,052 B2	5/2017	Al-Ali et al.	9,949,67		4/2018	
	,676 B2 ,679 B2		Culbert Schurman et al.	9,952,09 9,955,93		5/2018	Hotelling et al. Telfort
	,680 B2		Bruinsma et al.	9,965,94	6 B2	5/2018	Al-Ali
	,703 B2	6/2017		9,980,66 D820,86			Kiani et al. Muhsin et al.
	,286 B2 ,812 B2	6/2017 6/2017	Diab Presura	9,986,91			Lamego et al.
9,684	,900 B2	6/2017	Motoki et al.	9,986,95			Dalvi et al.
	,160 B2 ,719 B2	6/2017	Kiani Al-Ali et al.	9,989,56 9,993,20			Poeze et al. Al-Ali et al.
	,719 B2 ,737 B2	7/2017		10,007,75			Al-Ali et al.
9,697	,928 B2	7/2017	Al-Ali et al.	D822,21			Al-Ali et al.
	,546 B2 ,249 B2		Qian et al. Johnson et al.	D822,21 10,010,27			Barker et al. Al-Ali et al.
	,249 B2 ,937 B2		Qian et al.	10,010,27			Kiani et al.
9,717	,425 B2	8/2017	Kiani et al.	10,039,08	80 B2	7/2018	Miller et al.
9,717	,448 B2	8/2017	Frix et al.	10,039,48	32 B2	8/2018	Al-Ali et al.

(56)	Referen	ces Cited		10,335,068			Poeze et al.
ĪĪ	C DATENIT	DOCUMENTS		10,335,072 10,342,470			Al-Ali et al. Al-Ali et al.
0.	S. PAILINI	DOCOMENTS		10,342,487			Al-Ali et al.
10,039,491 B2		Thompson et al.		10,342,497	B2		Al-Ali et al.
10,052,037 B2 10,055,121 B2		Kinast et al.		10,349,895 10,349,898			Telfort et al. Al-Ali et al.
10,055,121 B. 10,058,275 B.		Chaudhri et al. Al-Ali et al.		10,354,504		7/2019	Kiani et al.
10,064,562 B	9/2018	Al-Ali		10,357,206			Weber et al.
10,066,970 B2		Gowreesunker et al. Lin et al.		10,357,209 10,366,787		7/2019 7/2019	Al-Ali Sampath et al.
10,076,257 B2 10,078,052 B2		Ness et al.		10,368,787		8/2019	Reichgott et al.
10,086,138 B	10/2018	Novak, Jr.		10,376,190			Poeze et al.
10,092,200 B2		Al-Ali et al.		10,376,191 10,383,520			Poeze et al. Wojtczuk et al.
10,092,244 B2 10,092,249 B2		Chuang et al. Kiani et al.		10,383,527		8/2019	
10,098,550 B2	2 10/2018	Al-Ali et al.		10,388,120			Muhsin et al.
10,098,591 B2		Al-Ali et al. Al-Ali et al.		10,390,716 10,398,320		8/2019 9/2019	Shimuta Kiani et al.
10,098,610 B2 D833,624 S		DeJong et al.		10,398,383	B2		van Dinther et al.
10,117,587 B2	2 11/2018	Han		10,405,804		9/2019	
10,123,726 B2		Al-Ali et al. Al-Ali et al.		10,406,445 10,413,666			Vock et al. Al-Ali et al.
10,130,289 B2 10,130,291 B2		Schurman et al.		10,416,079			Magnussen et al.
D835,282 S	12/2018	Barker et al.		10,420,493			Al-Ali et al.
D835,283 S		Barker et al.		D864,120 10,433,776		10/2019	Forrest et al.
D835,284 S D835,285 S		Barker et al. Barker et al.		10,441,181		10/2019	
10,149,616 B		Al-Ali et al.		10,448,844		10/2019	Al-Ali et al.
10,154,815 B2		Al-Ali et al.		10,448,871 10,456,038		10/2019	Al-Ali Lamego et al.
10,159,412 B2 10,165,954 B2		Lamego et al.		10,463,284			Al-Ali et al.
10,188,296 B	2 1/2019	Al-Ali et al.		10,463,340			Telfort et al.
10,188,331 B		Kiani et al.		10,470,695 10,471,159		11/2019	Al-Ali Lapotko et al.
10,188,348 B2 RE47,218 E		Al-Ali et al. Ali-Ali		10,478,107	B2		Kiani et al.
RE47,244 E		Kiani et al.		10,503,379			Al-Ali et al.
RE47,249 E		Kiani et al.		10,505,311 10,512,436		12/2019	Al-Ali et al. Muhsin et al.
10,194,847 B2 10,194,848 B3		Kiani et al.		10,524,706		1/2020	Telfort et al.
10,201,286 B	2 2/2019	Waydo		10,524,738		1/2020	
10,201,298 B2		Al-Ali et al.		10,531,811 10,531,819			Al-Ali et al. Diab et al.
10,205,272 B2 10,205,291 B2		Kiani et al. Scruggs et al.		10,531,835			Al-Ali et al.
10,213,108 B	2 2/2019	Al-Ali		10,532,174		1/2020	Al-Ali
10,215,698 B2 10,219,706 B2		Han et al.		10,537,285 10,542,903		1/2020 1/2020	Shreim et al. Al-Ali et al.
10,219,700 B2 10,219,746 B2		McHale et al.		10,548,561	B2	2/2020	Telfort et al.
10,219,754 B	3/2019	Lamego		10,555,678		2/2020 2/2020	Dalvi et al.
10,226,187 B2		Al-Ali et al.		10,568,514 10,568,553		2/2020	Wojtczuk et al. O'Neil et al.
10,226,576 B2 10,231,657 B2		Al-Ali et al.		RE47,882	E	3/2020	Al-Ali
10,231,670 B	2 3/2019	Blank et al.		10,575,779 10,582,886			Poeze et al. Poeze et al.
10,231,676 B2 RE47,353 E		Al-Ali et al. Kiani et al.		10,588,518		3/2020	
10,247,670 B2		Ness et al.		10,588,553	B2	3/2020	Poeze et al.
10,251,585 B		Al-Ali et al.		10,588,554 10,588,556			Poeze et al. Kiani et al.
10,251,586 B2 10,255,994 B2		Lamego Sampath et al.		10,588,530			Al-Ali et al.
10,258,265 B		Poeze et al.		10,608,817			Haider et al.
10,258,266 B		Poeze et al.		10,610,138 10,617,338			Poeze et al. Poeze et al.
10,265,024 B2 10,271,748 B2		Lee et al.		10,624,563			Poeze et al.
10,278,626 B		Schurman et al.		10,624,564			Poeze et al.
10,278,648 B2		Al-Ali et al.		10,631,765 10,638,961		5/2020	Poeze et al.
10,279,247 B2 10,285,626 B3		Kestelli et al.	20	02/0045836			Alkawwas
10,292,628 B	5/2019	Poeze et al.		02/0099279		7/2002	Pfeiffer et al.
10,292,657 B2		Abdul-Hafiz et al.		02/0111546 03/0036690			Cook et al. Geddes et al.
10,292,664 B2 10,299,708 B3		Al-All Poeze et al.		03/0158501			Uchida et al.
10,299,709 B	2 5/2019	Perea et al.	20	04/0054290	A1	3/2004	Chance
10,305,775 B2		Lamego et al.		04/0114783		6/2004	Spycher et al. Teller et al.
10,307,111 B2 10,325,681 B2		Muhsin et al. Sampath et al.		04/0133081 05/0020927		7/2004 1/2005	Blondeau et al.
10,327,337 B2		Triman et al.		05/0054940		3/2005	Almen
10,327,713 B2		Barker et al.		05/0116820		6/2005	
10,332,630 B2 10,335,033 B2				05/0192490 06/0005944			Yamamoto et al. Wang et al.
10,555,055 D	1/2019	AI-AII	20	00/0003344	73.1	1/2000	mang ci al.

(56)	Referen	ices Cited		2013/0060147			Welch et al.
11.0	DATENIT	DOCUMENTS		2013/0085346 2013/0096405		4/2013 4/2013	Lin et al. Garfio
0.5.	LAILMI	DOCOMENTS		2013/0096936			Sampath et al.
2006/0009607 A1		Lutz et al.		2013/0131474			Gu et al.
2006/0020180 A1		Al-Ali		2013/0190581 2013/0197328			Al-Ali et al. Diab et al.
2006/0025659 A1 2006/0161054 A1		Kiguchi et al. Reuss et al.		2013/0204112			White et al.
2006/0182659 A1		Unlu et al.		2013/0211214		8/2013	
2006/0253010 A1		Brady et al.		2013/0243021			Siskavich
2006/0258928 A1 2007/0073117 A1		Ortner et al. Raridan		2013/0296672 2013/0324808			O'Neil et al. Al-Ali et al.
2007/0073117 A1 2007/0100222 A1		Mastrototaro et al.		2013/0331670		12/2013	Kiani
2007/0106172 A1		Abreu		2013/0338461			Lamego et al.
2007/0149864 A1		Laakkonen		2014/0012100 2014/0034353			Al-Ali et al. Al-Ali et al.
2007/0208395 A1 2007/0238955 A1		Leclerc et al. Tearney et al.		2014/0051953			Lamego et al.
2007/0238935 A1 2007/0249916 A1		Pesach et al.		2014/0051955			Tiao et al.
2007/0260130 A1	11/2007			2014/0058230			Abdul-Hafiz et al.
2007/0293792 A1		Sliwa et al.		2014/0073887 2014/0073960			Petersen et al. Rodriguez-Llorente et al.
2008/0004513 A1 2008/0015424 A1		Walker et al. Bernreuter		2014/0077956			Sampath et al.
2008/0076980 A1		Hoarau		2014/0081100			Muhsin et al.
2008/0081966 A1		Debreczeny		2014/0081175 2014/0094667		3/2014	Telfort Schurman et al.
2008/0130232 A1 2008/0139908 A1	6/2008	Yamamoto		2014/0094007			Diab et al.
2008/0199908 A1 2008/0190436 A1		Jaffe et al.		2014/0107493	A1		Yuen et al.
2008/0221426 A1		Baker et al.		2014/0114199			Lamego et al.
2008/0221463 A1	9/2008			2014/0120564 2014/0121482			Workman et al. Merritt et al.
2009/0030327 A1 2009/0043180 A1		Chance Tschautscher et al.		2014/0121483		5/2014	
2009/0129102 A1		Xiao et al.		2014/0127137			Bellott et al.
2009/0163775 A1		Barrett et al.		2014/0129702 2014/0135588			Lamego et al. Al-Ali et al.
2009/0177097 A1 2009/0187085 A1	7/2009 7/2009	Ma et al.		2014/0133388			Al-Ali et al.
2009/0234206 A1		Gaspard et al.		2014/0163344	A1	6/2014	
2009/0247885 A1	10/2009	Suzuki et al.		2014/0163402			Lamego et al.
2009/0247984 A1		Lamego et al.		2014/0166076 2014/0171146			Kiani et al. Ma et al.
2009/0259114 A1 2009/0270699 A1		Johnson et al. Scholler et al.		2014/0171763		6/2014	
2009/0275813 A1	11/2009			2014/0180154			Sierra et al.
2009/0275844 A1	11/2009			2014/0180160 2014/0187973			Brown et al. Brown et al.
2009/0306487 A1 2010/0004518 A1		Crowe et al. Vo et al.		2014/0192177			Bartula et al.
2010/0004318 A1 2010/0030040 A1		Poeze et al.		2014/0194709			Al-Ali et al.
2010/0030043 A1	2/2010			2014/0194711		7/2014	Al-Ali et al.
2010/0113948 A1 2010/0130841 A1		Yang et al. Ozawa et al.		2014/0194766 2014/0206954			Yuen et al.
2010/0130841 A1 2010/0210925 A1		Holley et al.		2014/0206963	A1	7/2014	Al-Ali
2010/0305416 A1	12/2010	Bedard et al.		2014/0213864			Abdul-Hafiz et al.
2011/0001605 A1		Kiani et al.		2014/0221854 2014/0243627		8/2014 8/2014	Wai Diab et al.
2011/0004079 A1 2011/0004106 A1		Al-Ali et al. Iwamiya et al.		2014/0266790		9/2014	Al-Ali et al.
2011/0082711 A1		Poeze et al.		2014/0275808			Poeze et al.
2011/0085721 A1		Guyon et al.		2014/0275871 2014/0275872			Lamego et al. Merritt et al.
2011/0105854 A1 2011/0105865 A1		Kiani et al. Yu et al.		2014/0275881			Lamego et al.
2011/0208015 A1		Welch et al.		2014/0276013			Muehlemann et al.
2011/0213212 A1		Al-Ali		2014/0276116 2014/0288400			Takahashi et al. Diab et al.
2011/0230733 A1 2011/0237911 A1		Al-Ali Lamego et al.		2014/0296664			Bruinsma et al.
2011/0237911 A1 2011/0245697 A1		Miettinen		2014/0303520			Telfort et al.
2012/0059267 A1	3/2012	Lamego et al.		2014/0316217			Purdon et al.
2012/0150052 A1		Buchheim et al.		2014/0316218 2014/0316228			Purdon et al. Blank et al.
2012/0165629 A1 2012/0179006 A1		Merritt et al. Jansen et al.		2014/0323825			Al-Ali et al.
2012/0197093 A1		LeBoeuf et al.		2014/0323897			Brown et al.
2012/0197137 A1		Jeanne et al.		2014/0323898 2014/0330098			Purdon et al. Merritt et al.
2012/0209084 A1 2012/0227739 A1	9/2012	Olsen et al.		2014/0330099			Al-Ali et al.
2012/0227739 A1 2012/0283524 A1		Kiani et al.		2014/0333440		11/2014	
2012/0296178 A1	11/2012	Lamego et al.		2014/0336481			Shakespeare et al.
2012/0319816 A1	12/2012			2014/0343436		11/2014	
2012/0330112 A1 2013/0018233 A1		Lamego et al. Cinbis et al.		2014/0357966 2014/0361147		12/2014	Al-Ali et al.
2013/0018233 A1 2013/0023775 A1		Lamego et al.		2014/0301147		12/2014	
2013/0041591 A1	2/2013	Lamego		2015/0005600	A1	1/2015	Blank et al.
2013/0045685 A1	2/2013			2015/0011907			Purdon et al.
2013/0046204 A1	2/2013	Lamego et al.		2015/0018650	A1	1/2015	Al-Ali et al.
			0				

(56)	References Cited	2016/0378071		Rothkopf
211	PATENT DOCUMENT	2017/0007183 S 2017/0010858		Dusan et al. Prest et al.
0.5.	TATENT DOCUMENT	2017/0014083		Diab et al.
2015/0032029 A1	1/2015 Al-Ali et al.	2017/0024748		Haider
2015/0065889 A1	3/2015 Gandelman et a	1. 2017/0042488 2017/0055896		Muhsin Al-Ali et al.
2015/0073235 A1 2015/0080754 A1	3/2015 Kateraas et al. 3/2015 Purdon et al.	2017/0074897		Mermel et al.
2015/0087936 A1	3/2015 Al-Ali et al.	2017/0084133		Cardinali et al.
2015/0094546 A1	4/2015 Al-Ali	2017/0086689 2017/0086742		Shui et al. Harrison-Noonan et al.
2015/0099950 A1 2015/0101844 A1	4/2015 Al-Ali et al. 4/2015 Al-Ali et al.	2017/0086742		Bushnell et al.
2015/0101644 A1 2015/0106121 A1	4/2015 Al-Ali et al. 4/2015 Muhsin et al.	2017/0094450		Tu et al.
2015/0119725 A1	4/2015 Martin et al.	2017/0143281		
2015/0173671 A1	6/2015 Paalasmaa et al	. 2017/0147774 2017/0164884		Kıanı Culbert et al.
2015/0196249 A1 2015/0216459 A1	7/2015 Brown et al. 8/2015 Al-Ali et al.	2017/0104884		Presura
2015/0255001 A1	9/2015 Haughav et al.	2017/0172476		Schilthuizen
2015/0257689 A1	9/2015 Al-Ali et al.	2017/0173632		Al-Ali
2015/0281424 A1	10/2015 Vock et al.	2017/0196464 2017/0196470		Jansen et al. Lamego et al.
2015/0318100 A1 2015/0351697 A1	11/2015 Rothkopf et al. 11/2015 Weber et al.	2017/0202505		Kirenko et al.
2015/0351704 A1	12/2015 Kiani et al.	2017/0209095		Wagner et al.
2015/0366472 A1	12/2015 Kiani	2017/0228516 2017/0245790		Sampath et al. Al-Ali et al.
2015/0366507 A1 2015/0374298 A1	12/2015 Blank 12/2015 Al-Ali et al.	2017/0243790		Gowreesunker et al.
2015/0374298 A1 2015/0380875 A1	12/2015 Al-Air et al.	2017/0251974	A1 9/2017	Shreim et al.
2016/0000362 A1	1/2016 Diab et al.	2017/0273619		Alvarado et al.
2016/0007930 A1	1/2016 Weber et al.	2017/0281024 2017/0293727		Narasimhan et al. Klaassen et al.
2016/0019360 A1 2016/0022160 A1	1/2016 Pahwa et al. 1/2016 Pi et al.	2017/0311891		Kiani et al.
2016/0023245 A1	1/2016 Zadesky et al.	2017/0325698		Allec et al.
2016/0029932 A1	2/2016 Al-Ali	2017/0325744 2017/0340209		Allec et al. Klaassen et al.
2016/0029933 A1 2016/0038045 A1	2/2016 Al-Ali et al. 2/2016 Shapiro	2017/0340209		Sullivan et al.
2016/0038043 A1 2016/0041531 A1	2/2016 Mackie et al.	2017/0340293		Al-Ali et al.
2016/0045118 A1	2/2016 Kiani	2017/0347885		Tan et al.
2016/0051157 A1	2/2016 Waydo	2017/0354332 2017/0354795		Lamego Blahnik et al.
2016/0051158 A1 2016/0051205 A1	2/2016 Silva 2/2016 Al-Ali et al.	2017/0358239		Arney et al.
2016/0058302 A1	3/2016 Raghuram et al	2017/0358240		Blahnik et al.
2016/0058309 A1	3/2016 Han	2017/0358242 2017/0360306		Thompson et al. Narasimhan et al.
2016/0058310 A1 2016/0058312 A1	3/2016 Iijima 3/2016 Han et al.	2017/0366657		Thompson et al.
2016/0058338 A1	3/2016 Schurman et al.	2018/0008146	A1 1/2018	Al-Ali et al.
2016/0058356 A1	3/2016 Raghuram et al			Clavelle et al. Mathew et al.
2016/0058370 A1 2016/0066823 A1	3/2016 Raghuram et al 3/2016 Al-Ali et al.	2018/0023287		Shahparnia et al.
2016/0066824 A1	3/2016 Al-Ali et al.	2018/0049694	A1 2/2018	Singh Alvarado et al.
2016/0066879 A1	3/2016 Telfort et al.	2018/0050235		Tan et al.
2016/0071392 A1	3/2016 Hankey et al.	2018/0055375 2018/0055390		Martinez et al.
2016/0072429 A1 2016/0073967 A1	3/2016 Kiani et al. 3/2016 Lamego et al.	2018/0055439	A1 3/2018	Pham et al.
2016/0106367 A1	4/2016 Jorov et al.	2018/0056129		Narasimha Rao et al.
2016/0113527 A1	4/2016 Al-Ali et al.	2018/0064381 2018/0070867		Shakespeare et al. Smith et al.
2016/0143548 A1 2016/0154950 A1	5/2016 Al-Ali 6/2016 Nakajima et al.	2010/0070151		Allec et al.
2016/0157780 A1	6/2016 Rimminen et al	2018/0078182		Chen et al.
2016/0166210 A1	6/2016 Al-Ali	2018/0082767 2018/0085068		Al-Ali et al. Telfort
2016/0192869 A1 2016/0196388 A1	7/2016 Kiani et al. 7/2016 Lamego	2018/0087937		Al-Ali et al.
2016/0190388 A1 2016/0197436 A1	7/2016 Lanlego 7/2016 Barker et al.	2018/0103874	A1 4/2018	Lee et al.
2016/0213281 A1	7/2016 Eckerbom et al			
2016/0213309 A1	7/2016 Sannholm et al.	2018/0110469 2018/0125368		Maani et al. Lamego et al.
2016/0256058 A1 2016/0256082 A1	9/2016 Pham et al. 9/2016 Ely et al.	2018/0125430		Al-Ali et al.
2016/0267238 A1	9/2016 Nag	2018/0132769		Weber et al.
2016/0270735 A1	9/2016 Diab et al.	2018/0146901 2018/0146902		Al-Ali et al. Kiani et al.
2016/0283665 A1 2016/0287107 A1	9/2016 Sampath et al. 10/2016 Szabados et al.	2018/0140902		Sullivan et al.
2016/0287107 A1 2016/0287181 A1	10/2016 Szabados et al. 10/2016 Han et al.	2018/0153442		Eckerbom et al.
2016/0287786 A1	10/2016 Kiani	2018/0153446		
2016/0296173 A1	10/2016 Culbert	2018/0153448		Weber et al.
2016/0296174 A1 2016/0310027 A1	10/2016 Isikman et al. 10/2016 Han	2018/0164853 2018/0168491		Myers et al. Al-Ali et al.
2016/031002/ A1 2016/0314260 A1	10/2016 Han 10/2016 Kiani	2018/01084917		
2016/0327984 A1	11/2016 Al-Ali et al.	2018/0192924	A1 7/2018	Al-Ali
2016/0367173 A1	12/2016 Dalvi et al.	2018/0192953		Shreim et al.
2016/0378069 A1	12/2016 Rothkopf	2018/0196514	A1 7/2018	Allec et al.
		10		

(56)	Referen	ces Cited		0325722 A1 0350506 A1	10/2019 11/2019	Kiani et al. Al-Ali
U.S.	PATENT	DOCUMENTS	2019/0	357813 A1	11/2019	Poeze et al.
2010/0100071 41	7/2010	D 1 1 1		)357823 A1 )357824 A1	11/2019 11/2019	Reichgott et al. Al-Ali
2018/0199871 A1 2018/0206795 A1		Pauley et al. Al-Ali		358524 A1	11/2019	Kiani
2018/0206815 A1	7/2018	Telfort		)365294 A1		Poeze et al.
2018/0213583 A1 2018/0214090 A1		Al-Ali Al-Ali et al.		)374139 A1 )374173 A1	12/2019	Kiani et al. Kiani et al.
2018/0214030 A1 2018/0216370 A1		Ishiguro et al.	2019/0	)374713 A1	12/2019	Kiani et al.
2018/0218792 A1		Muhsin et al. Al-Ali et al.		)386908 A1 )388039 A1	12/2019 12/2019	Lamego et al.
2018/0225960 A1 2018/0228414 A1		Shao et al.	2020/0	0000338 A1	1/2020	Lamego et al.
2018/0238718 A1	8/2018			0000415 A1 0015716 A1		Barker et al. Poeze et al.
2018/0238734 A1 2018/0242853 A1		Hotelling et al. Al-Ali		0021930 A1		Iswanto et al.
2018/0242923 A1	8/2018	Al-Ali et al.		0037453 A1		Triman et al.
2018/0242926 A1 2018/0247353 A1		Muhsin et al. Al-Ali et al.		0037891 A1 0037966 A1	2/2020	Kiani et al. Al-Ali
2018/0247535 A1 2018/0247712 A1		Muhsin et al.	2020/0	0046257 A1	2/2020	Eckerbom et al.
2018/0256087 A1		Al-Ali et al.		0054253 A1 0060591 A1		Al-Ali et al. Diab et al.
2018/0279956 A1 2018/0285094 A1		Waydo et al. Housel et al.		0060628 A1		Al-Ali et al.
2018/0296161 A1	10/2018	Shreim et al.		0060629 A1	2/2020	
2018/0300919 A1 2018/0310822 A1		Muhsin et al. Lndorf et al.		0060869 A1 0074819 A1	2/2020	Telfort et al.  Muhsin et al.
2018/0310823 A1		Al-Ali et al.	2020,0	707 1015 111	3,2020	Trianom et al.
2018/0317826 A1 2018/0317841 A1	11/2018	Muhsin Novak, Jr.		FOREIG	N PATE	NT DOCUMENTS
2018/0337841 A1 2018/0333055 A1		Lamego et al.	CN	101484	065 B	11/2011
2018/0333087 A1	11/2018		CN	103906		7/2014
2019/0000317 A1 2019/0015023 A1		Muhsin et al. Monfre	EP	419	223 208 A1	3/1991
2019/0029574 A1		Schurman et al.	EP EP		349 A1	12/1994 5/1997
2019/0029578 A1 2019/0058280 A1		Al-Ali et al. Al-Ali et al.	EP	0 781	527	7/1997
2019/0069813 A1	3/2019		EP EP		936 A2 432 A1	12/1998 6/1999
2019/0076028 A1 2019/0082979 A1		Al-Ali et al. Al-Ali et al.	EP	0985	373 A1	3/2000
2019/0082979 A1 2019/0090760 A1		Kinast et al.	EP EP	1 518	494 805 A1	3/2005 5/2005
2019/0090764 A1	3/2019	Al-Ali	EP		609 B1	8/2006
2019/0117070 A1 2019/0117139 A1		Muhsin et al. Al-Ali et al.	EP		989 A1	12/2007
2019/0117141 A1	4/2019	Al-Ali	EP EP		213 A2 666 A1	1/2008 1/2008
2019/0117930 A1 2019/0122763 A1	4/2019	Al-Ali Sampath et al.	EP	2165	196 A1	3/2010
2019/0122703 A1 2019/0133525 A1		Al-Ali et al.	EP GB	2 277 2243	440 691 A	1/2011 11/1991
2019/0142283 A1		Lamego et al. Telfort et al.	JP	05-325	705 A	12/1993
2019/0142344 A1 2019/0150856 A1		Kiani et al.	JP JP	08-185 H 09257		7/1996 10/1997
2019/0167161 A1		Al-Ali et al.	JP	H 10314		12/1998
2019/0175019 A1 2019/0192076 A1		Al-Ali et al. McHale et al.	JP	H 1170		3/1999
2019/0200941 A1	7/2019	Chandran et al.	JP JP	H 11235	326 B2 320 A	7/1999 8/1999
2019/0201623 A1 2019/0209025 A1	7/2019 7/2019	Kiani Al-Ali	JP	2001-66	990	3/2001
2019/0214778 A1	7/2019	Scruggs et al.	JP JP	2001-087 2002-500		4/2001 1/2002
2019/0216319 A1 2019/0216379 A1		Poeze et al. Al-Ali et al.	JP	2003-024	276 A	1/2003
2019/0210379 A1 2019/0221966 A1		Kiani et al.	JP JP	2003-508 2003-265		3/2003 9/2003
2019/0223804 A1		Blank et al.	JP	2004329		11/2004
2019/0231199 A1 2019/0231241 A1		Al-Ali et al. Al-Ali et al.	JP JP	2005160 2005270		6/2005 10/2005
2019/0231270 A1		Abdul-Hafiz et al.	JP		147 B2	2/2006
2019/0239787 A1 2019/0239824 A1		Pauley et al. Muhsin et al.	JP	2006102		4/2006
2019/0254578 A1	8/2019	Lamego	JP JP	2006-177 2006-198		7/2006 8/2006
2019/0261857 A1 2019/0269370 A1		Al-Ali Al-Ali et al.	JP	3803	351 B2	8/2006
2019/0274627 A1		Al-Ali et al.	JP JP	2007-389 2007319		11/2007 12/2007
2019/0274635 A1		Al-Ali et al. Dalvi et al.	JP	2008-099	222 A	4/2008
2019/0290136 A1 2019/0298270 A1		Al-Ali et al.	JP KR	5756 20070061		6/2015 6/2007
2019/0304601 A1	10/2019	Sampath et al.	KR		079 B1	9/2007
2019/0304605 A1 2019/0307377 A1	10/2019	Al-Ali Perea et al.	KR WO	20100091		8/2010
2019/0307377 AT 2019/0320906 AT	10/2019		WO WO	WO 1993/12 WO 94/23		7/1993 10/1994
2019/0320959 A1	10/2019		WO	WO 1995/000	070 A1	1/1995
2019/0320988 A1	10/2019	Ahmed et al.	WO	WO 1996/27	323	9/1996

### US 10,702,194 B1

Page 12

#### (56)References Cited FOREIGN PATENT DOCUMENTS WO WO 1997/009923 A1 3/1997 WO 1999/000053 WO 1/1999 WO WO 1999/01704 7/1999 WO WO 1999/063883 A1 12/1999 wo WO 2000/25112 5/2000 WO WO 2000/028892 A1 5/2000 WO WO 2001/09589 2/2001 WO WO 2006/060949 A1 6/2006 WO WO 2006/079862 A2 8/2006 WO WO 2006/090371 A2 8/2006 WO WO 2006/113070 A2 10/2006 WO WO 2007/004083 A1 1/2007 WO WO 2007/017266 A2 2/2007 WO WO 2008/107238 A1 9/2008 WO WO 2009/001988 A1 12/2008 WO WO 2009/137524 11/2009 WO WO 2010/003134 1/2010 WO WO 2011/069122 A1 6/2011 WO WO 2013/030744 A1 3/2013 WO WO 2013/106607 A2 7/2013 WO WO 2013/181368 A1 12/2013 WO WO 2014/115075 A1 7/2014

WO 2014/149781

WO 2014/158820

WO 2014/153200 A1

WO 2014/178793 A1

WO 2014/184447 A1

WO 2015/187732 A1

WO 2016/066312 A1

WO

WO

WO

WO

WO

WO

WO

#### OTHER PUBLICATIONS

9/2014

9/2014

10/2014

11/2014

11/2014

12/2015

5/2016

Jan. 9, 2020 Complaint for (1) Patent Infringement (2) Trade Secret Misappropriation and (3) Ownership of Patents and Demand for Jury Trial, *Masimo Corporation and Cercacor Laboratories, Inc.* v. *Apple Inc.*, Case No. 8:20-cv-00048, 64 pages.

Mar. 25, 2020 First Amended Complaint for (1) Patent Infringement (2) Trade Secret Misappropriation (3) Correction of Inventorship and (4) Ownership of Patents and Demand for Jury Trial, and including Exhibits 13-24 (Exhibits 1-12 and 25-31 comprise copies of publicly available U.S. patents and U.S. patent application publications, and are not included herein for ease of transmission), *Masimo Corporation and Cercacor Laboratories, Inc.* v. *Apple Inc.*, Case No. 8:20-cv-00048, pgs. 1-94, 983-1043 (total of 156 pages). U.S. Appl. No. 12/534,827, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Aug. 3, 2009.

U.S. Appl. No. 16/449,143, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Jun. 21, 2019

U.S. Appl. No. 16/534,956, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Aug. 7, 2019.

U.S. Appl. No. 16/541,987, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Aug. 15, 2019.

U.S. Appl. No. 16/725,478, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Dec. 23, 2019.

U.S. Appl. No. 16/725,292, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Dec. 23, 2019.

U.S. Appl. No. 16/829,510, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 25, 2020.

U.S. Appl. No. 16/829,578, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 25, 2020.

U.S. Appl. No. 16/834,467, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 30, 2020

U.S. Appl. No. 16/834,538, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 30, 2020.

U.S. Appl. No. 16/834,533, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 30, 2020.

U.S. Appl. No. 14/064.055, Multi-Stream Sensor for Noninvasive Measurement of Blood Constituents, filed Oct. 25, 2013.

U.S. Appl. No. 15/660,743, Noise Shielding for a Noninvasive Device, filed Jul. 26, 2017.

U.S. Appl. No. 16/805,605, Noise Shielding for a Noninvasive Device, filed Feb. 28, 2020.

U.S. Appl. No. 12/497,506, Heat Sink for Noninvasive Medical Sensor, filed Jul. 2, 2009.

U.S. Appl. No. 16/532,061, Physiological Measurement Devices, Systems, and Methods, filed Aug. 5, 2019.

U.S. Appl. No. 16/532,065, Physiological Measurement Devices, Systems, and Methods, filed Aug. 5, 2019.

U.S. Appl. No. 16/791,955, Physiological Measurement Devices, Systems, and Methods, filed Feb. 14, 2020.

U.S. Appl. No. 16/791,963, Physiological Measurement Devices, Systems, and Methods, filed Feb. 14, 2020.

U.S. Appl. No. 16/835,712, Physiological Measurement Devices, Systems, and Methods, filed Mar. 31, 2020.

U.S. Appl. No. 16/835,772, Physiological Measurement Devices, Systems, and Methods, filed Mar. 31, 2020.

PCT International Search Report, App. No. PCT/US2010/047899, Date of Actual Completion of Search: Jan. 26, 2011, 4 pages.

International Search Report and Written Opinion for PCT/US2009/049638, dated Jan. 7, 2010.

International Search Report issued in Application No. PCT/US2009/052756, dated Feb. 10, 2009 in 14 pages.

International Preliminary Report on Patentability and Written Opinion of the International Searching Authority issued in Application No. PCT US2009/049638, dated Jan. 5, 2011 in 9 pages.

International Preliminary Report on Patentability and Written Opinion of the International Searching Authority issued in Application No. PCT/US2009/052756, dated Feb. 8, 2011 in 8 pages.

International Preliminary Report on Patentability and Written Opinion for International Application No. PCT/US2016/040190, dated Jan. 2, 2018, in 7 pages.

Burritt, Mary F.; Current Analytical Approaches to Measuring Blood Analytes; vol. 36; No. 8(B); 1990.

Hall, et al., Jeffrey W.; Near-Infrared Spectrophotometry: A New Dimension in Clinical Chemistry; vol. 38; No. 9; 1992.

Kuenstner, et al., J. Todd; Measurement of Hemoglobin in Unlysed Blood by Near-Infrared Spectroscopy; vol. 48; No. 4, 1994.

Manzke, et al., B., Multi Wavelength Pulse Oximetry in the Measurement of Hemoglobin Fractions; SPIE, vol. 2676, Apr. 24, 1996. Naumenko, E. K.; Choice of Wavelengths for Stable Determination of Concentrations of Hemoglobin Derivatives from Absorption Spectra of Erythrocytes; vol. 63; No. 1; pp. 60-66 Jan.-Feb. 1996; Original article submitted Nov. 3, 1994.

Schmitt, Joseph M.; Simple Photon Diffusion Anaylsis of the Effects of Multiple Scattering on Pulse Oximetry; Mar. 14, 1991; revised Aug. 30, 1991.

Schmitt, et al., Joseph M.; Measurement of Blood Hematocrit by Dual-Wavelength near-IR Photoplethysmography; vol. 1641; 1992. Schnapp, et al., L.M.; Pulse Oximetry. Uses and Abuses.; Chest 1990; 98; 1244-1250 DOI 10.1378/Chest.98.5.1244.

http://www.masimo.com/rainbow/pronto.htm Noninvasive & Immediate Hemoglobin Testing, printed on Aug. 20, 2009.

http://www.masimo.com/pulseOximeter/Rad5.htm; Signal Extraction Pulse Oximeter, printed on Aug. 20, 2009.

http://blogderoliveira.blogspot.com/2008\_02\_01\_archive.html; Ricardo Oliveira, printed on Aug. 20, 2009.

http://www.masimo.com/rad-57/; Noninvasive Measurement of Methemoglobin, Carboxyhemoglobin and Oxyhemoglobin in the blood. Printed on Aug. 20, 2009.

http://amivital.ugr.es/blog/?tag+spo2; Monitorizacion de la hemoglobina . . .y mucho mas, printed on Aug. 20, 2009.

http://www.masimo.com/spco/; Carboxyhemoglobin Noninvasive > Continuous > Immediate, printed on Aug. 20, 2009.

### US 10,702,194 B1

Page 13

### (56) References Cited

#### OTHER PUBLICATIONS

http://www.masimo.com/Partners/Welchallyn.htm; Welch Allyn Expands Patient Monitor Capabilities with Masimo Pulse Oximetry Technology, printed on Aug. 20, 2009.

http://www.masimo.com/pulseOximeter/PPO.htm; Masimo Personal Pulse Oximeter, printed on Aug. 20, 2009.

http://www.masimo.com/generalFloor/system.htm; Masimo Patient SafetyNet System at a Glance, printed on Aug. 20, 2009.

http://www.masimo.com/partners/Graseby.htm; Graseby Medical Limited, printed on Aug. 20, 2009.

Japanese Office Action, re JP Application No. 2011-516895, dated Sep. 2, 2014, with translation.

Japanese Notice of Allowance, re JP Application No. 2011-516895, dated May 12, 2015, no translation.

European Office Action issued in application No. 10763901.5 dated Jan. 11, 2013.

European Office Action issued in application No. 10763901.5 dated Aug. 27, 2014.

European Office Action issued in application No. 10763901.5 dated Aug. 6, 2015.

European Office Action issued in Application No. 09791157.2, dated Jun. 20, 2016.

Kanukurthy et al., "Data Acquisition Unit for an Implantable Multi-Channel Optical Glucose Sensor", Electro/Information Technology Conference, Chicago, IL, USA, May 17-20, 2007, pp. 1-6. Konig et al., "Reflectance Pulse Oximetry—Principles and Obstetric Application in the Zurich System", Journal of Clinical Monitoring and Computing, vol. 14, No. 6, Aug. 1998, pp. 403-412. Smith, "The Pursuit of Noninvasive Glucose: 'Hunting the Deceitful Turkey'", 2006.

Small et al., "Data Handling Issues for Near-Infrared Glucose Measurements", http://www.ieee.org/organizations/pubs/newsletters/leos/apr98/datahandling.htm, accessed Nov. 27, 2007.

D. C. Zheng and Y. T. Zhang, "A ring-type device for the noninvasive measurement of arterial blood pressure," Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No. 03CH37439), Sep. 17-21, 2003, Cancun, pp. 3184-3187 vol. 4.

Sokwoo Rhee et al., "Artifact-Resistant Power-Efficient Design of Finger-Ring Plethysmographic Sensors," IEEE Transactions on Biomedical Engineering, Jul. 2001, pp. 795-805, vol. 48, No. 7.

L. Xu et al., "An integrated wrist-worn routine monitoring system for the elderly using BSN," 2008 5th International Summer School and Symposium on Medical Devices and Biosensors, Hong Kong, 2008, pp. 45-48.

J Kraitl et al., "An optical device to measure blood components by a photoplethysmographic method," Journal of Optics A: Pure and Applied Optics. 7, 2005, pp. S318-S324.

K. Nakajima et al., "Monitoring of heart and respiratory rates by photoplethysmography using digital filtering technique," Med. Eng. Phy. vol. 18, No. 5, pp. 365-372, 1996.

Russell Dresher, "Wearable Forehead Pulse Oximetry: Minimization of Motion and Pressure Artifacts," May 3, 2006, 93 pages. Sonnia Maria López Silva et al., "Near-infrared transmittance pulse oximetry with laser diodes," Journal of Biomedical Optics vol. 8 No. 3, Jul. 2003, pp. 525-533.

Fabio Buttussi et al., "MOPET: A context-aware and user-adaptive wearable system for fitness training," Artificial Intelligence in Medicine 42, 2008, pp. 153-163.

Stephen A. Mascaro et al., "Photoplethysmograph Fingernail Sensors for Measuring Finger Forces Without Haptic Obstruction," IEEE Transactions on Robotics and Automation, vol. 17, No. 5, Oct. 2001, pp. 698-708.

Stephen A. Mascaro et al., "Measurement of Finger Posture and Three-Axis Fingertip Touch Force Using Fingernail Sensors," IEEE International Conference on Robotics and Automation, 2002, pp. 1-11.

Akira Sakane et al., "Estimating Arterial Wall Impedance using a Plethysmogram," IEEE 2003, pp. 580-585.

Nuria Oliver et al., "HealthGear: A Real-time Wearable System for Monitoring and Analyzing Physiological Signals," Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks 2006 IEEE, pp. 1-4.

Yuan-Hsiang Lin et al., "A wireless PDA-based physiological monitoring system for patient transport," IEEE Transactions on Information Technology in Biomedicine, vol. 8, No. 4, pp. 439-447, Dec. 2004

R. Fensli et al., "A Wireless ECG System for Continuous Event Recording and Communication to a Clinical Alarm Station," Conf Proc IEEE Eng Med Biol Soc, 2004, pp. 1-4.

E. Higurashi et al., "An integrated laser blood flowmeter," Journal of Lightwave Technology, vol. 21, No. 3, pp. 591-595, Mar. 2003. T. Kiyokura etal., "Wearable Laser Blood Flowmeter for Ubiquitous Healthcare Service," 2007 IEEE/LEOS International Conference on Optical MEMS and Nanophotonics, Hualien, 2007, pp. 4-5.

Takumi Morita et al., "Integrated Blood Flowmeter Using Micromachining Technology," Dec. 2004, pp. 77-80.

Eiji Higurashi et al., "Hybrid integration technologies for optical micro-systems", Proc. SPIE 5604, Optomechatronic Micro/Nano Components, Devices, and Systems, Oct. 25, 2004, pp. 67-73.

L. Grajales et al., "Wearable multisensor heart rate monitor," International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06), Cambridge, MA, 2006, pp. 4-157.

N. Townsend, "Pulse Oximetry," Medical Electronics, 2001, pp. 32-42.

Nonin Medical, Inc., "Operator's Manual—Models 8600F0 and 8600F0M Pulse Oximeters," 2005, 25 pages.

C. J. Pujary, "Investigation of Photodetector Optimization in Reducing Power Consumption by a Noninvasive Pulse Oximeter Sensor," Worcester Polytechnic Institute, Jan. 16, 2004, 133 pages.

B. McGarry et al., "Reflections on a candidate design of the user-interface for a wireless vital-signs monitor," Proceedings of DARE 2000 on Designing Augmented Reality Environments, Jan. 2000, pp. 33-40.

J. C. D. Conway et al., "Wearable computer as a multi-parametric monitor for physiological signals," Proceedings IEEE International Symposium on Bio-Informatics and Biomedical Engineering, Arlington, VA, USA, 2000, pp. 236-242.

J. A. Tamada et al., "Noninvasive Glucose Monitoring: Comprehensive Clinical Results," JAMA, Nov. 17, 1999, vol. 282, No. 19, pp. 1839-1844.

B.-H. Yang et al., "Development of the ring sensor for healthcare automation," Robotics and Autonomous Systems, 2000, pp. 273-281.

Laukkanen RM et al., "Heart Rate Monitors: State of the Art," Journal of Sports Science, Jan. 1998, pp. S3-S7.

S. Warren et al., "Designing Smart Health Care Technology into the Home of the Future," Workshops on Future Medical Devices: Home Care Technologies for the 21st Century, Apr. 1999, 19 pages.

A. C. M. Dassel et al., "Reflectance Pulse Oximetry at the Forehead Improves by Pressure on the Probe," Journal of Clinical Monitoring, vol. 11, No. 4, Jul. 1995, pp. 237-244.

B-H. Yang et al., "A Twenty-Four Hour Tele-Nursing System Using a Ringer Sensor," Proceedings of 1998 IEEE International Conference on Robotics and Automation, May 16-20, 1998, 6 pages.

S. Rhee et al., "The Ring Sensor: a New Ambulatory Wearable Sensor for Twenty-Four Hour Patient Monitoring," Proceedings of the 20<sup>th</sup> Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Oct. 29-Nov. 1, 1998, 4 pages. S. Rhee et al., "Design of a Artifact-Free Wearable Plethysmographic Sensor," 21<sup>st</sup> Annual International Conference IEEE Engineering in Medicine and Biology Society, Oct. 13-16, 1999, p. 786.

T. Martin et al., "Issues in Wearable Computing for Medical Montioring Applications: A Case Study of a Wearable ECG Monitoring Device," In Proceedings of International Symposium of Wearable Computers (ISWC'00), Feb. 2000, pp. 43-49.

S. Rhee et al., "Artifact-Resistant, Power Efficient Design of Finger-Ring Plethysmographic Sensors, Part I: Design and Analysis," 22<sup>nd</sup> Annual International Conference IEEE Engineering in Medicine and Biology Society, Jul. 23-28, 2000, pp. 2792-2795.

C. Pujary et al., "Photodetector Size Considerations in the Design of a Noninvasive Reflectance Pulse Oximeter for Telemedicine

### US 10,702,194 B1

Page 14

#### (56) References Cited

#### OTHER PUBLICATIONS

Applications," Proceedings of IEEE Annual Northeast Bioengineering Conference, 2003, pp. 148-149.

M. Savage et al., "Optimizing Power Consumption in the Design of a Wearable Wireless Telesensor: Comparison of Pulse Oximeter Modes," Proceedings of IEEE 29<sup>th</sup> Annual Nonheust Bioengineering Conference, 2003, pp. 150-151.

A. Tura et al., "A Wearable Device with Wireless Bluetooth-based Data Transmission," Measurement Science Review, vol. 3, Sec. 2, 2003, pp. 1-4.

R. Paradiso, "Wearable Health Care System for Vital Signs Monitoring," In Proceedings of IEEE International Conference on Information Technology Applications in Biomedicine, May 2003, pp. 283-286.

H.H. Asada et al., "Mobile Monitoring with Wearable Photoplethysmographic Biosensors," IEEE Engineering in Medicine and Biology Magazine, May/Jun. 2003, pp. 28-40.

Y. Mendelson et al., "Minimization of LED Power Consumption in the Design of a Wearable Pulse Oximeter," Proceedings of the IASTED International Conference Biomedical Engineering, Jun. 25-27, 2003, 6 pages.

Y. Mendelson et al., "Measurement Site and Photodetector Size Considerations in Optimizing Power Consumption of a Wearable Reflectance Pulse Oximeter," Proceedings of the 25<sup>th</sup> Annual International Conference of the IEEE EMBS, Sep. 17-21, 2003, pp. 3016-3019.

D. Marculescu et al., "Ready to Ware," IEEE Spectrum, vol. 40, Issue 10, Oct. 2003, pp. 28-32.

P. Celka et al., "Motion Resistant Earphone Located Infrared Based Hearth Rate Measurement Device," In Proceeding of the 2<sup>nd</sup> International Conference on Biomedical Engineering, Innsbruck, Austria, Feb. 16-18, 2004, pp. 582-585.

D. Konstantas etal., "Mobile Patient Monitoring: The MobiHealth System," In Proceedings of International Conference on Medical and Care Compunetics, NCC'04, Feb. 2004, 8 pages.

S. Pentland, "Healthwear: Medical Technology Becomes Wearable," IEEE Computer Society, vol. 37, Issue 5, May 2004, pp. 34-41.

P. Branche et al., "Signal Quality and Power Consumption of a New Prototype Reflectance Pulse Oximeter Sensor," Proceeding of the 31th Annual Northeast Bioengineering Conference, Hoboken, NJ, IEEE, 2005, pp. 1-2.

U. Anliker et al., "AMON: A Wearable Multiparameter Medical Monitoring and Alert System," IEEE Transactions on Information Technology in Biomedicine, Jan. 2005, pp. 1-11.

P. T. Gibbs et al., "Active Motion Artifact Cancellation for Wearable Health Monitoring Sensors Using Collocated MEMS Accelerometers," Proceedings of SPIE Smart Structures and Materials: Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems, May 17, 2005, pp. 811-819.

C. W. Mundt et al., "A Multiparameter Wearable Physiologic Monitoring System for Space and Terrestrial Applications," IEEE Transactions on Information Technology in Biomedicine, vol. 9, No. 3, Sep. 2005, pp. 382-391.

Y. Mendelson et al., "A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 912-915.

B-S. Lin et al., "RTWPMS: A Real-Time Wireless Physiological Monitoring System," IEEE Transactions on Information Technology in Biomedicine, vol. 10, No. 4, Oct. 2006, pp. 647-656.

T. Torfs et al., "Body-Heat Powered Autonomous Pulse Oximeter," IEEE Sensors 2006, EXCO, Oct. 22-25, 2006, pp. 427-430.

P.S. Pandian et al., "Smart Vest: Wearable Multi-Parameter Remote Physiological Monitoring System," Medical Engineering & Physics 30, 2008. pp. 466-477.

G. Tamannagari, "Power Efficient Design of Finder-Ring Sensor for Patient Monitoring," Master of Science in Electrical Engineering, The University of Texas at San Antonio, College of Engineering, Department of Electrical Engineering, Dec. 2008, 74 pages.

M. Yamashita et al., "Development of a Ring-Type Vital Sign Telemeter," Biotelemetry XIII, Mar. 26-31, 1995, pp. 145-150.

P. Renevey et al., "Wrist-Located Pulse Detection Using IR Signals, Activity and Nonlinear Artifact Cancellation," Proceedings of the 23<sup>rd</sup> Annual EMBS International Conference, Oct. 25-28, 2001, pp. 3030-3033.

Y. Mendelson et al., "A Mobile PDA-Based Wireless Pulse Oximeter," Proceedings of the IASTED International Conference Telehealth, Jul. 19-21, 2005, pp. 1-6.

P. Shaltis et al., "Novel Design for a Wearable, Rapidly Depolyable, Wireless Noninvasive Triage Sensor," Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27<sup>th</sup> Annual Conference, Sep. 1-4, 2005, pp. 3567-3570.

Y-S. Yan et al., An Efficient Motion-Resistant Method for Wearable Pulse Oximeter, IEEE Transactions on Information Technology in Biomedicine, vol. 12, No. 3, May 2008, pp. 399-405.

P. C. Branche et al., "Measurement Reproducibility and Sensor Placement Considerations in Designing a Wearable Pulse Oximeter for Military Applications," IEEE, 2004, pp. 216-217.

G. Comtois, "A Comparative Evaluation of Adaptive Noise Cancellation Algorithms for Minimizing Motion Artifacts in a Forehead-Mounted Wearable Pulse Oximeter," Proceedings of the 29<sup>th</sup> Annual international Conference of the IEEE EMBS, Aug. 23-26, 2007, pp. 1528-1531.

G. Comtois et al., "A Noise Reference Input to an Adaptive Filter Algorithm for Signal Processing in a Wearable Pulse Oximeter," IEEE, 2007, pp. 106-107.

R. P. Dresher et al., "A New Reflectance Pulse Oximeter Housing to Reduce Contact Pressure Effects," IEEE, 2006, pp. 49-50.

R. P. Dresher et al., "Reflectance Forehead Pulse Oximetry: Effects on Contact Pressure During Walking," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 3529-3532.

W. S. Johnston et al., "Extracting Breathing Rate Information from a Wearable Reflectance Pulse Oximeter Sensor," Proceedings of the 26<sup>th</sup> Annual International Conference of the IEEE EMBS, Sep. 1-5, 2004, pp. 5388-5391.

W. Johnston et al., "Extracting Heart Rate Variability from a Wearable Reflectance Pulse Oximeter," IEEE, 2005, pp. 1-2.

W. S. Johnston et al., "Investigation of Signal Processing Algorithms for an Embedded Microcontroller-Based Wearable Pulse Oximeter," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 5888-5891.

P. Lukowicz et al., "AMON: A Wearable Medical Computer for High Risk Patient," Proceedings of the 6<sup>th</sup> International Symposium on Wearable Computers (ISWC'02), 2002, pp. 1-2.

P. Lukowicz et al., "The WearARM Modular, Low-Power Computing Core," IEEE Micro, May-Jun. 2001, pp. 16-28.

Y. Mendelson et al., "Accelerometery-Based Adaptive Noise Cancellation for Remote Physiological Monitoring by a Wearable Pulse Oximeter," Proceedings of the 3<sup>rd</sup> IASTED International Conference Telehealth, May 31-Jun. 1, 2007, pp. 28-33.

U.S. Pat. No. 10,258,265, U.S. Appl. No. 16/449.143.

U.S. Pat. No. 10,258,266, U.S. Appl. No. 16/534,956.

U.S. Pat. No. 10,292,628, U.S. Appl. No. 16/541.987.

U.S. Pat. No. 10,299,708, U.S. Appl. No. 16/725,478.

U.S. Pat. No. 10,376,190, U.S. Appl. No. 16/725,292.

U.S. Pat. No. 10,376,191, U.S. Appl. No. 16/829,510.

U.S. Pat. No. 10,588,553, U.S. Appl. No. 16/829,578.

U.S. Pat. No. 10,588,554, U.S. Appl. No. 16/829,536.

U.S. Appl. No. 16/834,467.

U.S. Appl. No. 16/834,538.

U.S. Appl. No. 16/834,533.

U.S. Pat. No. 10,470,695, U.S. Appl. No. 16/532,061.

U.S. Appl. No. 16/532,065.

U.S. Appl. No. 16/791,955.

U.S. Appl. No. 16/791,963.

U.S. Appl. No. 16/835,712. U.S. Appl. No. 16/835,772.

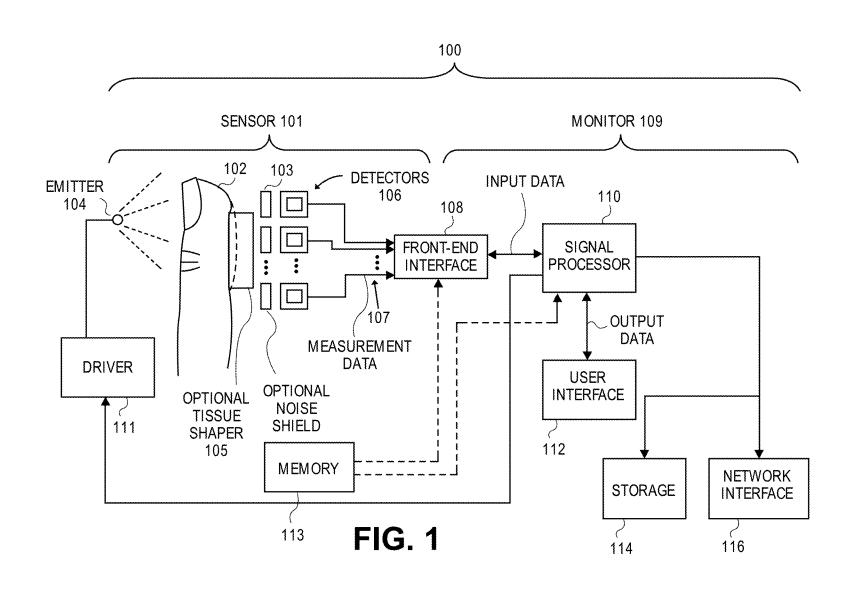
U.S. Pat. No. 8,457,703, U.S. Appl. No. 15/820,082.

U.S. Pat. No. 10,433,776, U.S. Appl. No. 16/174,130.

U.S. Appl. No. 16/871,874, Physiological Measurement Devices, Systems, and Methods, filed May 11, 2020.

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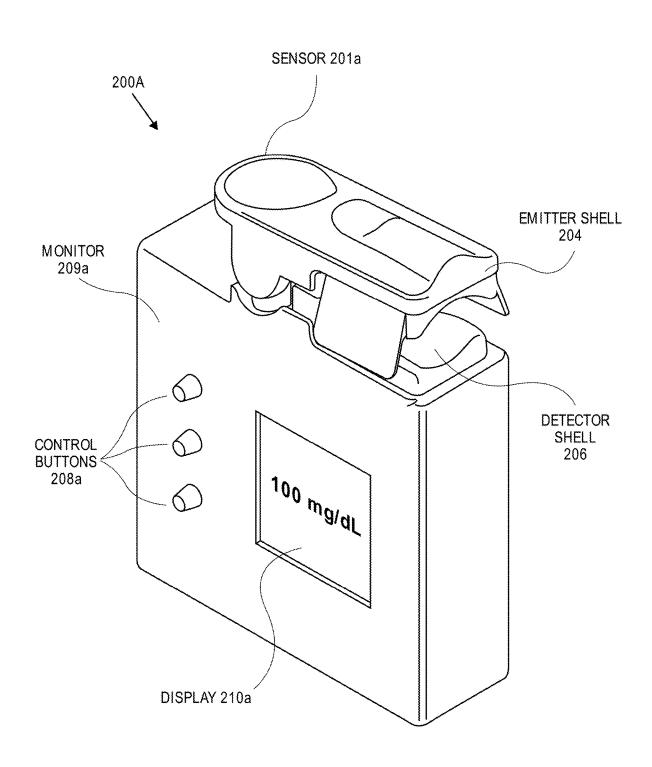


FIG. 2A

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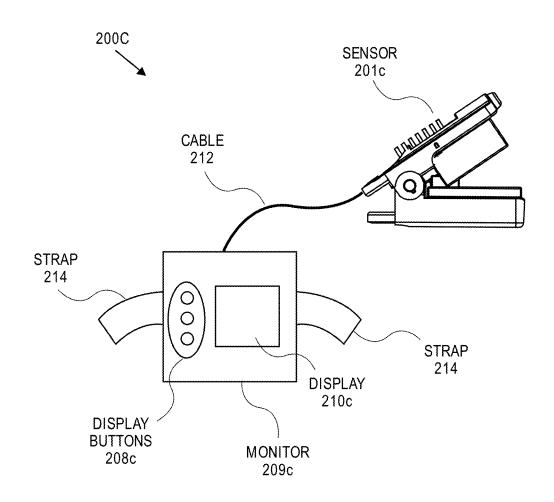
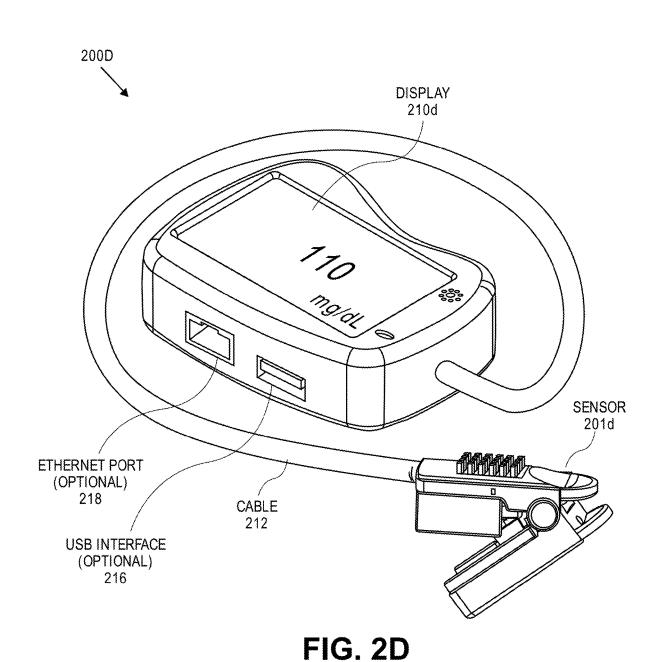


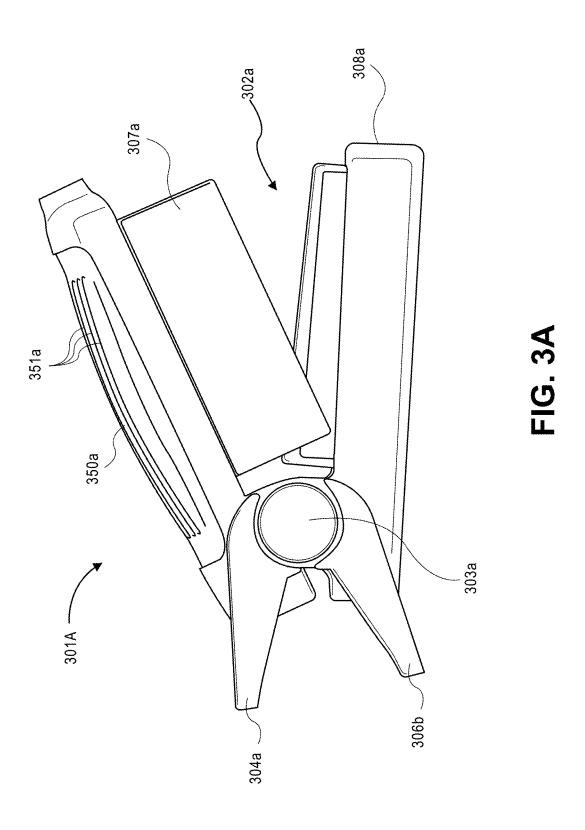
FIG. 2C

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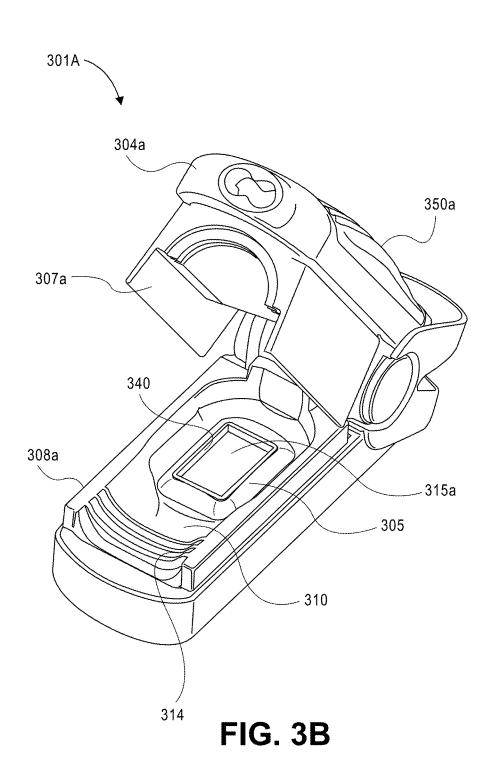


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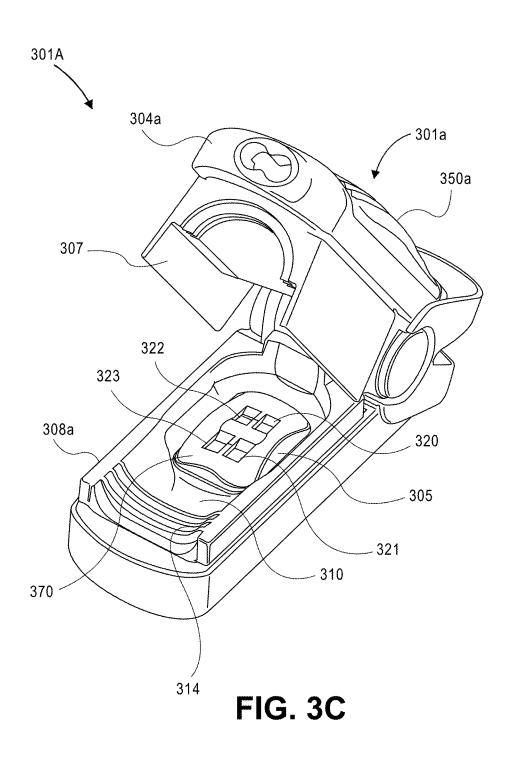
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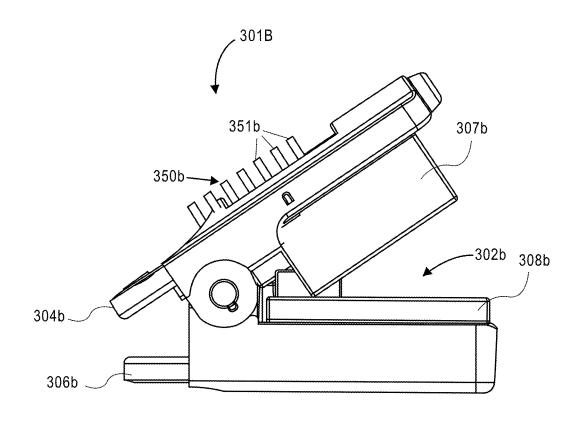


FIG. 3D

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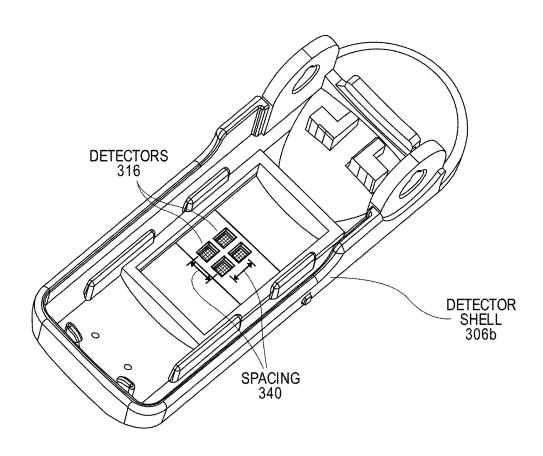
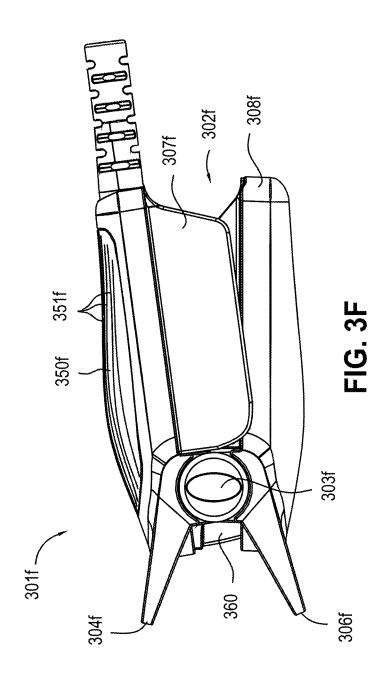


FIG. 3E

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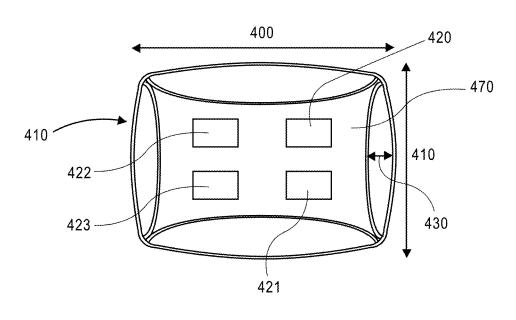


FIG. 4A

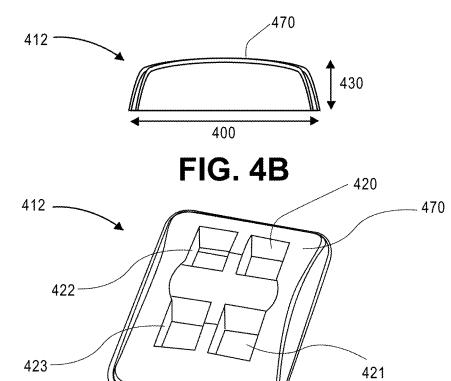
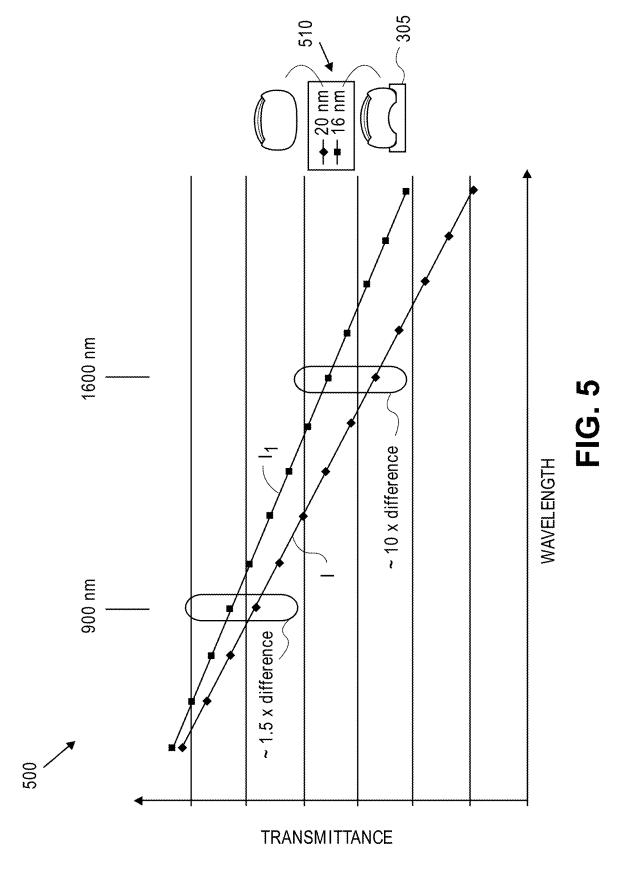


FIG. 4C

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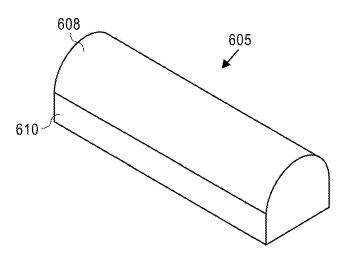


FIG. 6A

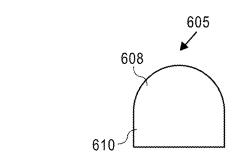


FIG. 6B

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FIG. 6C

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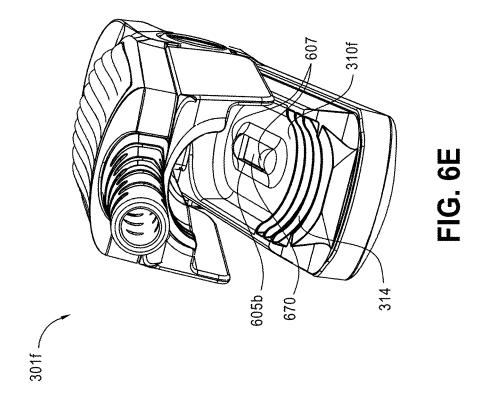
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FIG. 6D

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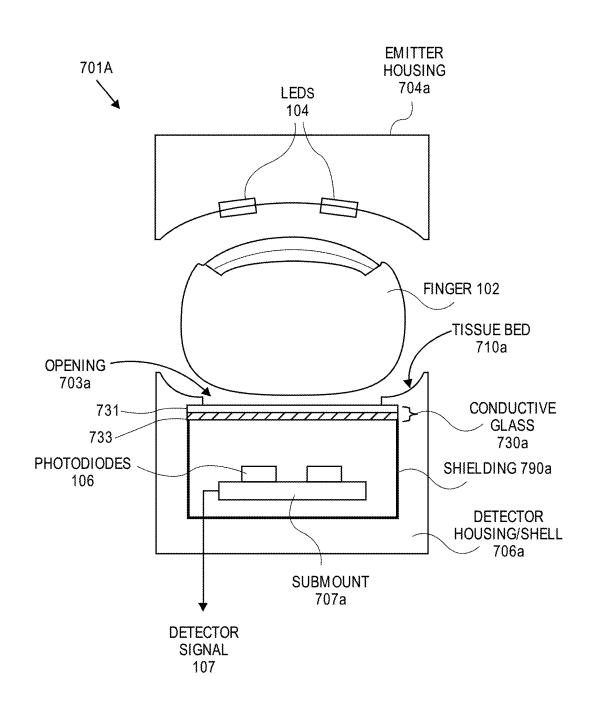


FIG. 7A

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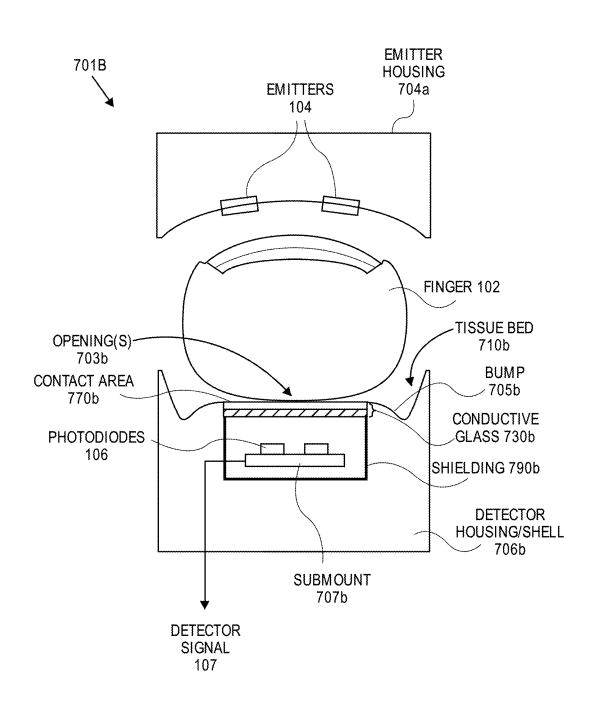
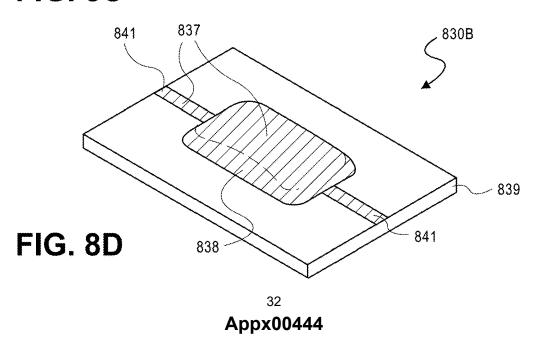


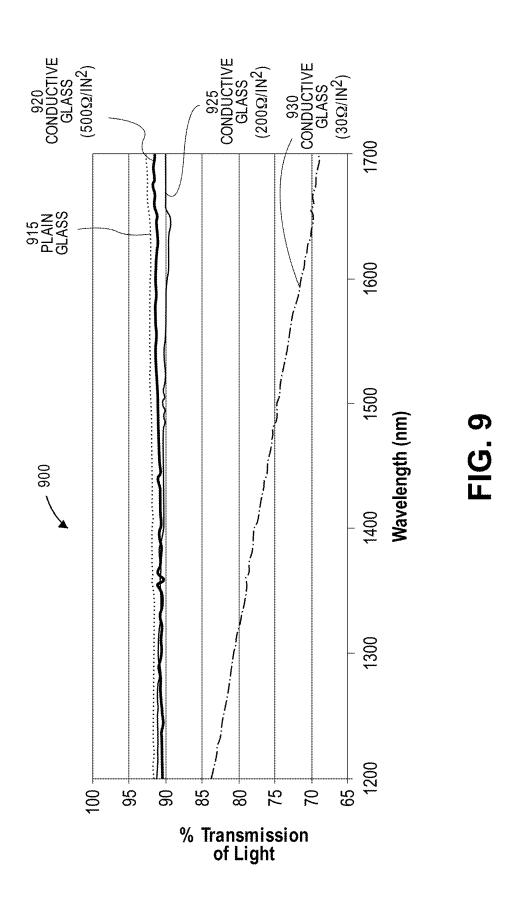
FIG. 7B

U.S. Patent US 10,702,194 B1 Jul. 7, 2020 **Sheet 18 of 65** 730 731 733 820 FIG. 8A -731 733 830A FIG. 8B **731** 733 -835

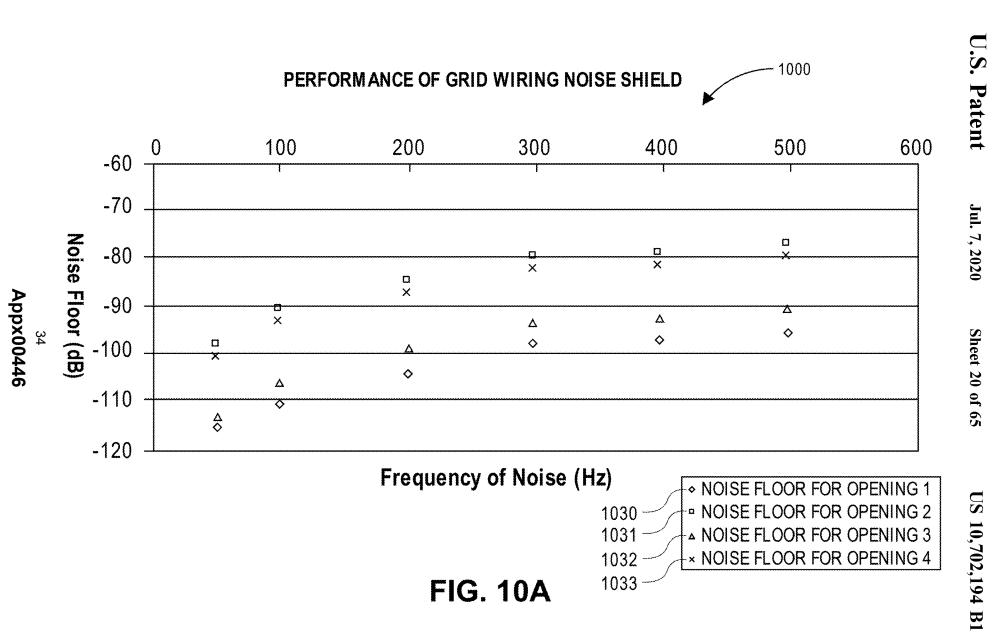
FIG. 8C

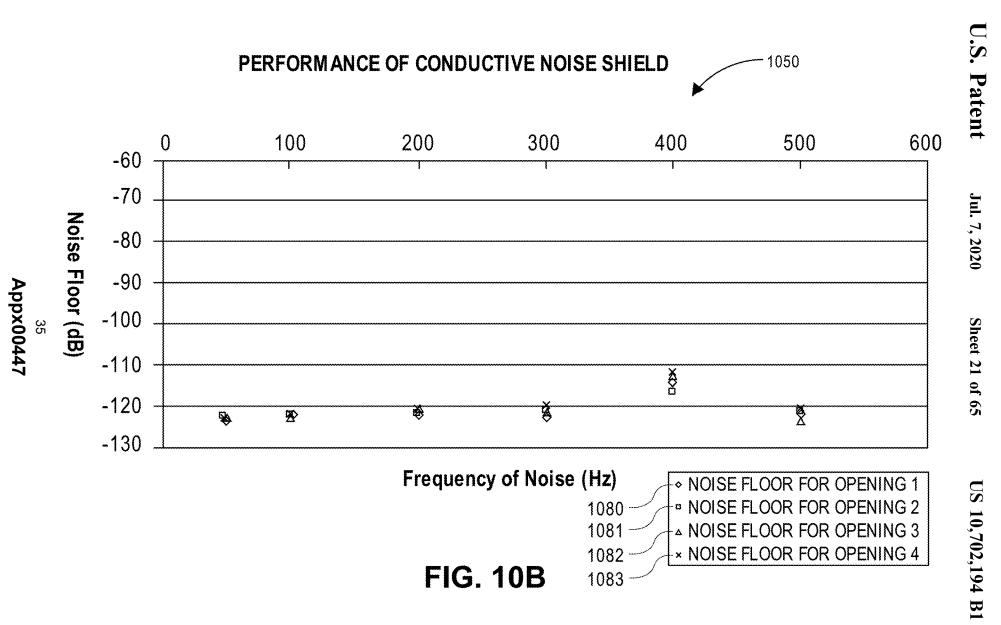


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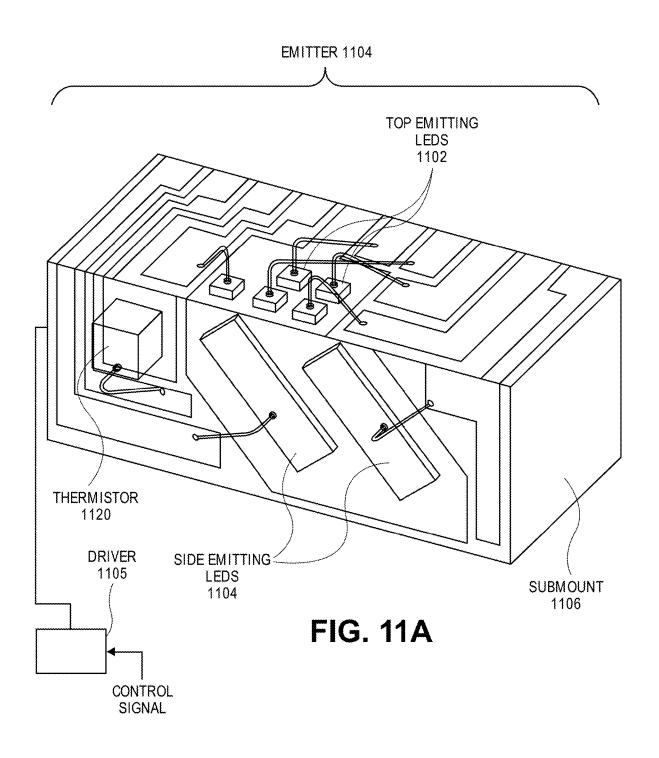




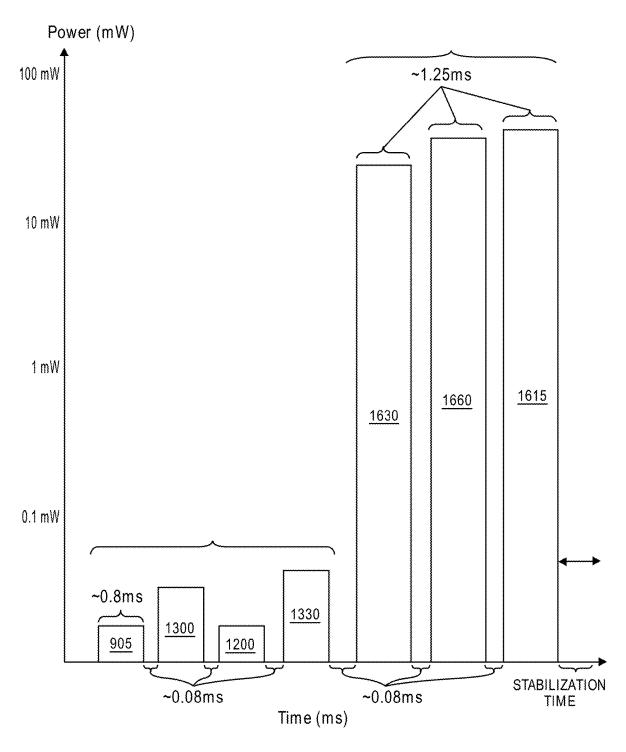
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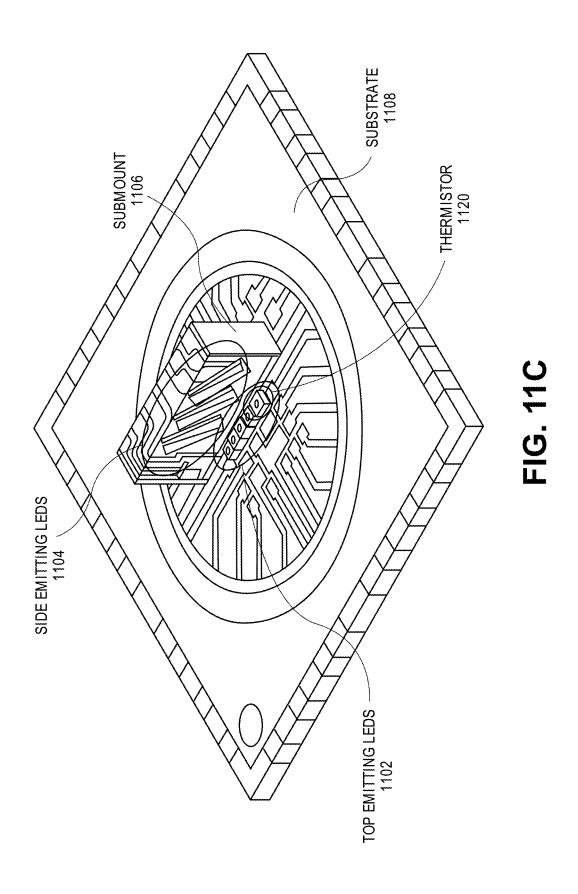


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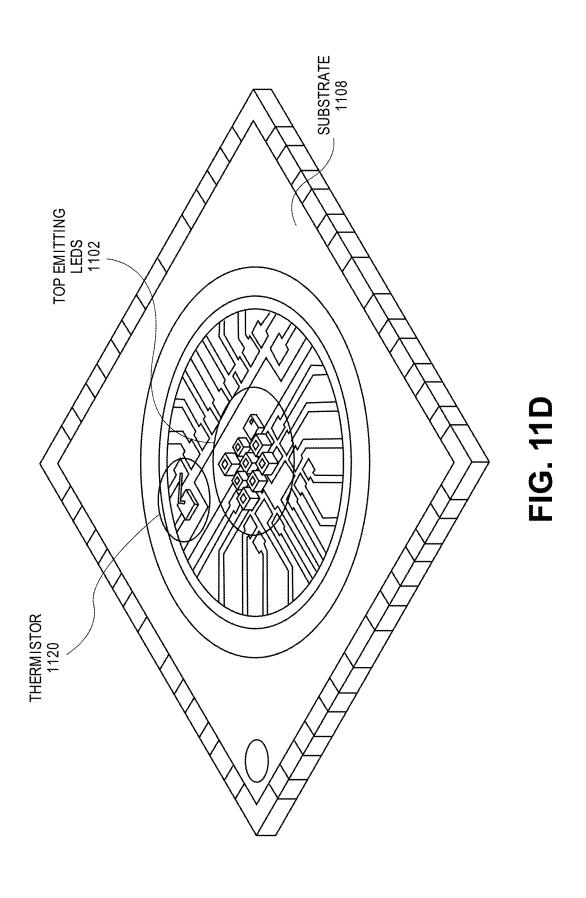
**FIG. 11B** 

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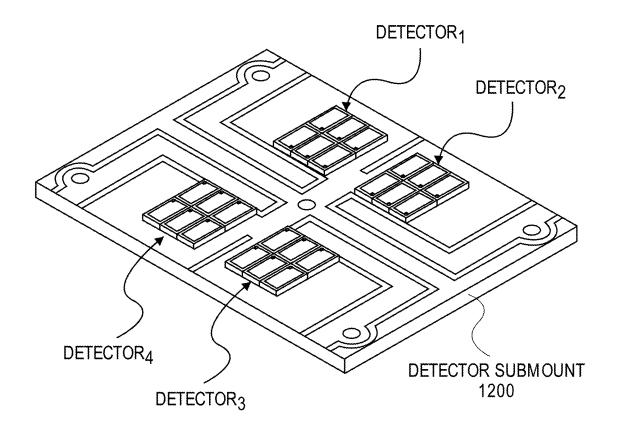


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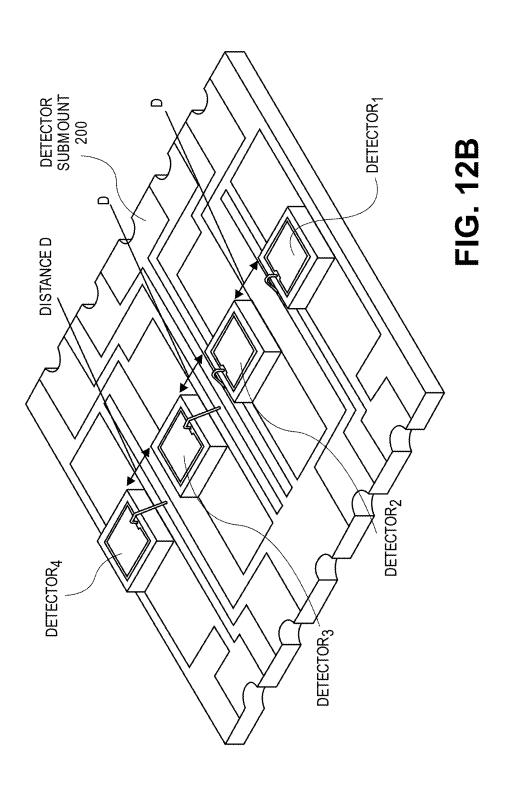


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**FIG. 12A** 

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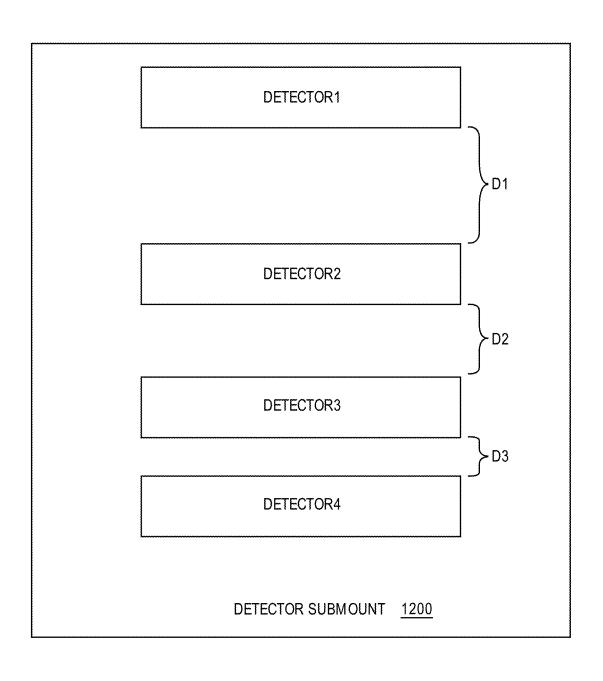
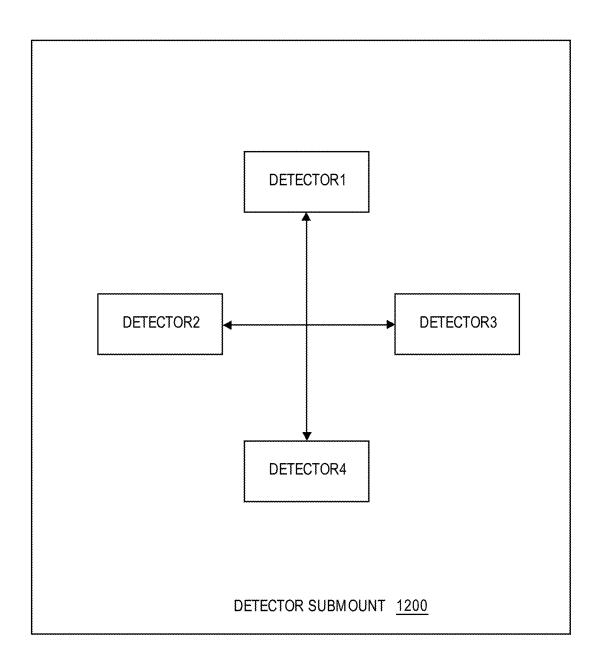


FIG. 12C

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**FIG. 12D** 

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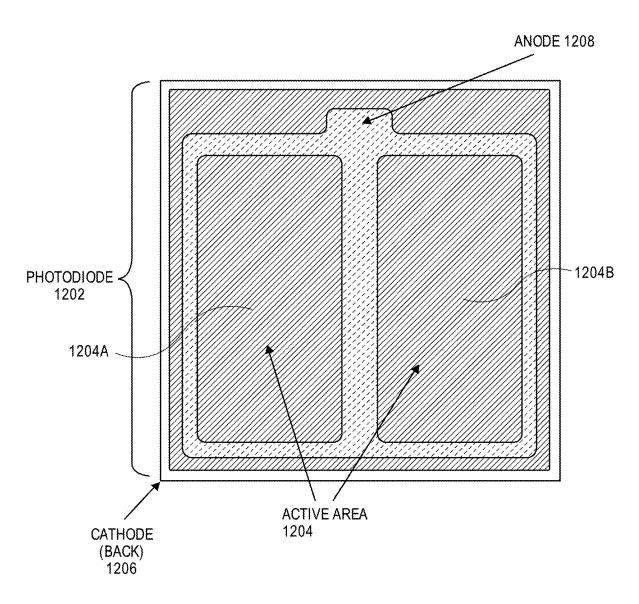


FIG. 12E

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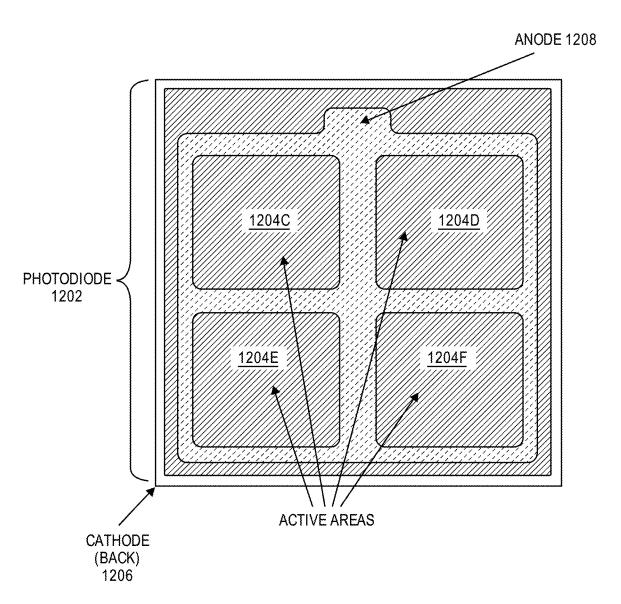
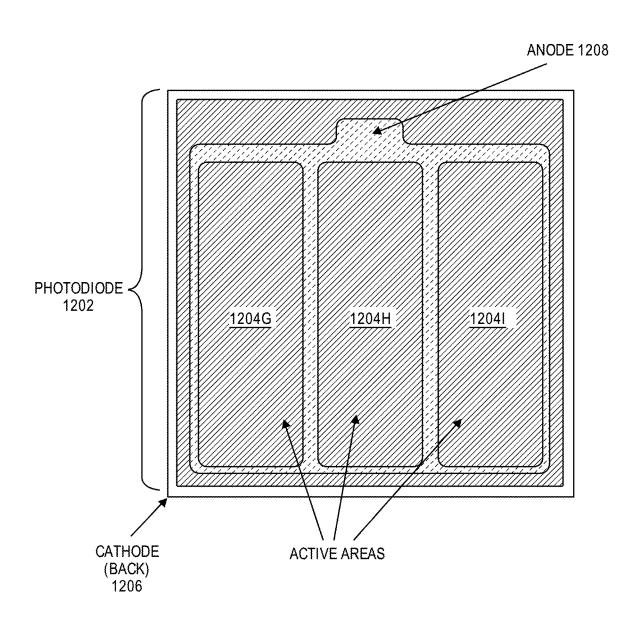


FIG. 12F

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**FIG. 12G** 

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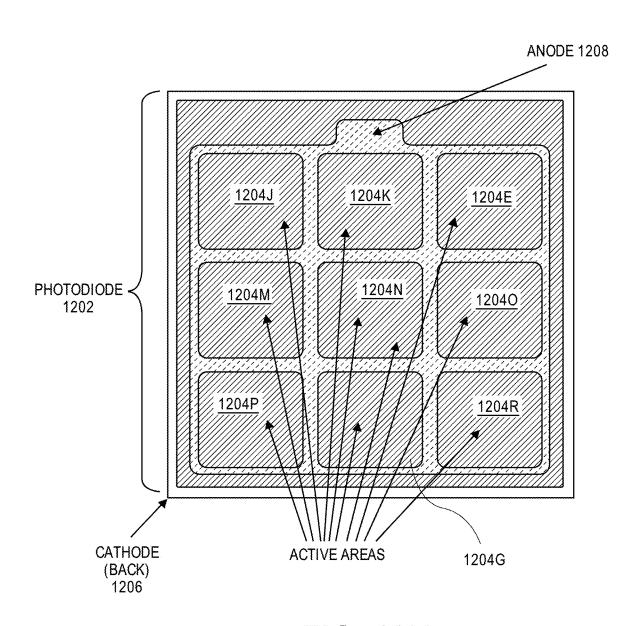
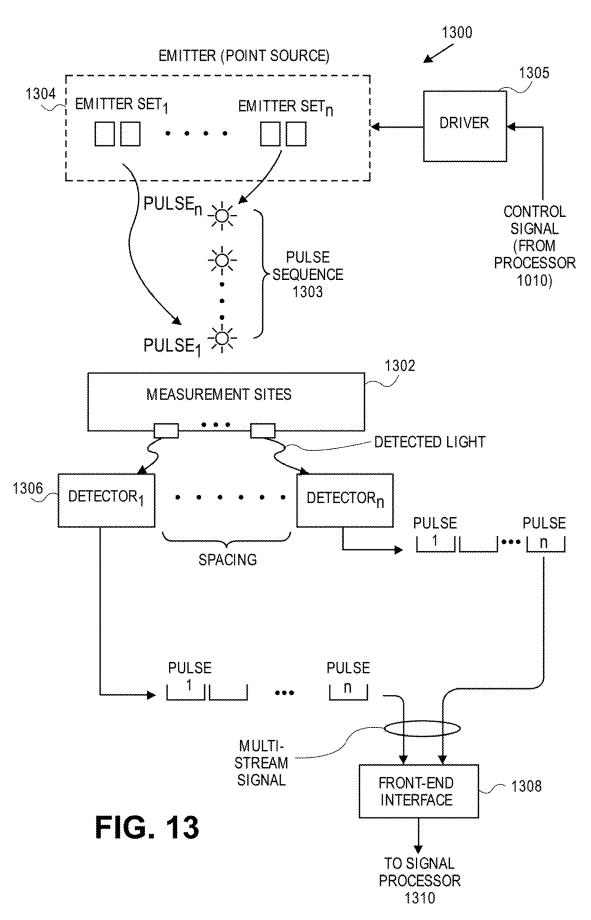
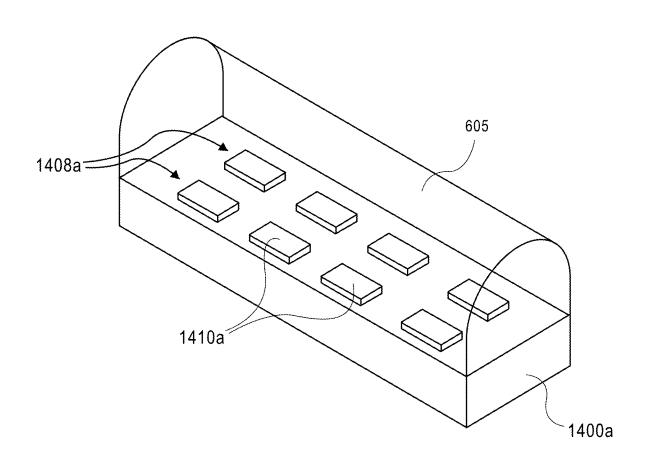


FIG. 12H

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**FIG. 14A** 

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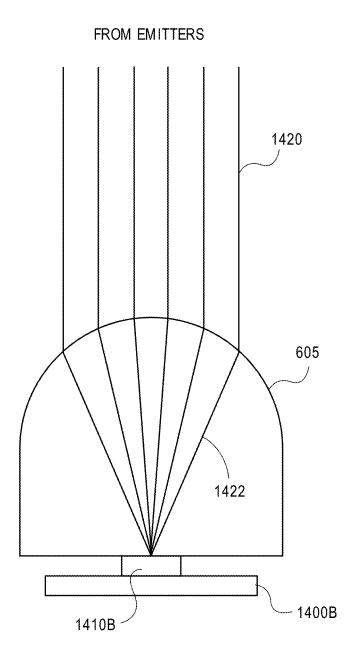


FIG. 14B

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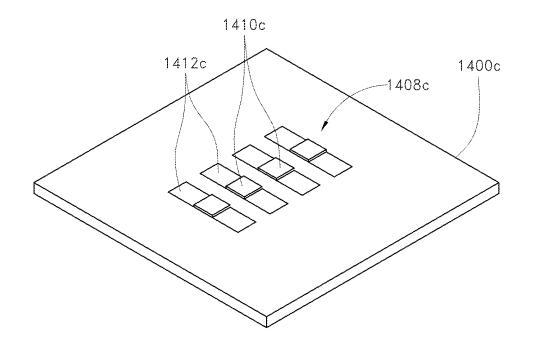
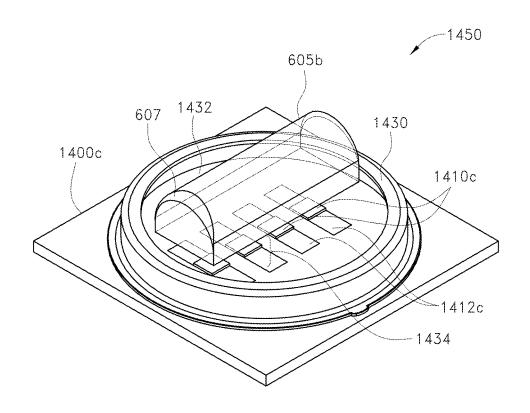


FIG. 14C

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**FIG. 14D** 

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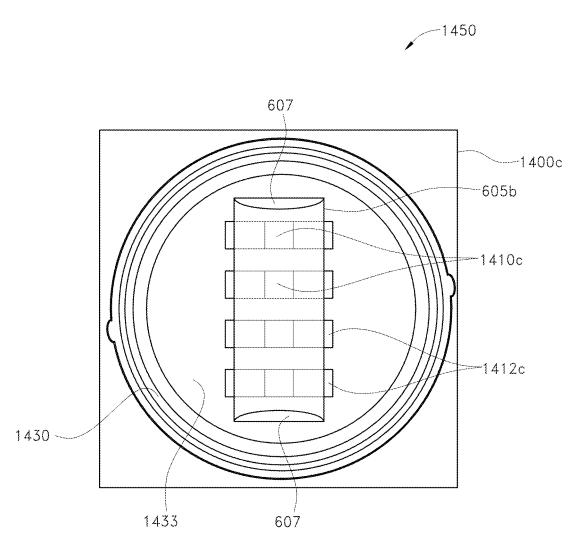


FIG. 14E

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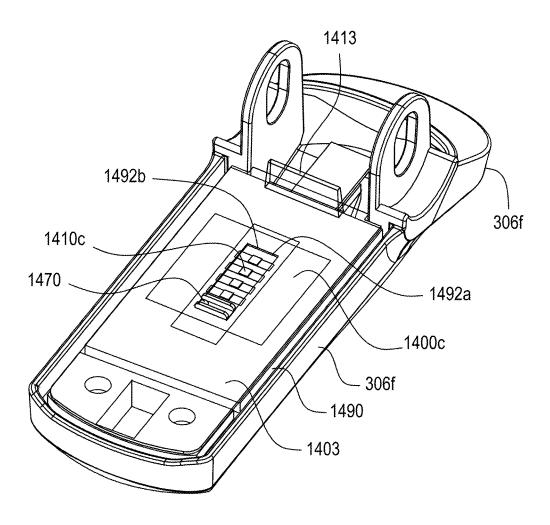


FIG. 14F

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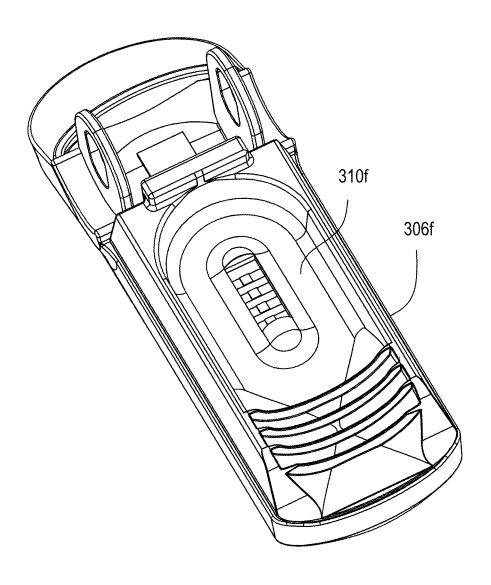


FIG. 14G

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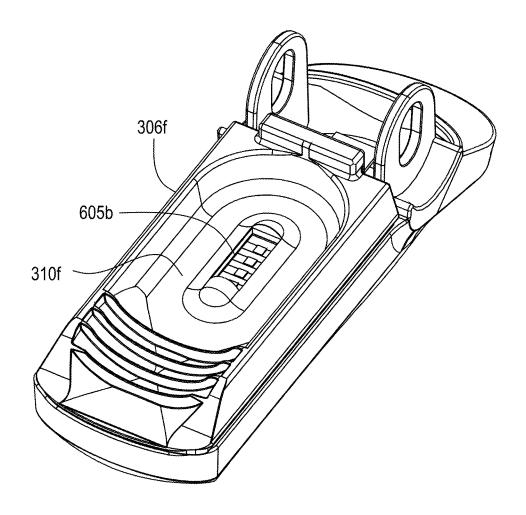


FIG. 14H

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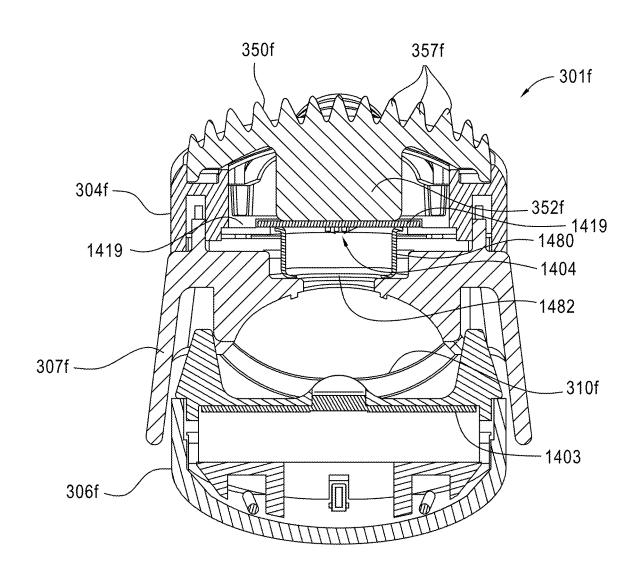
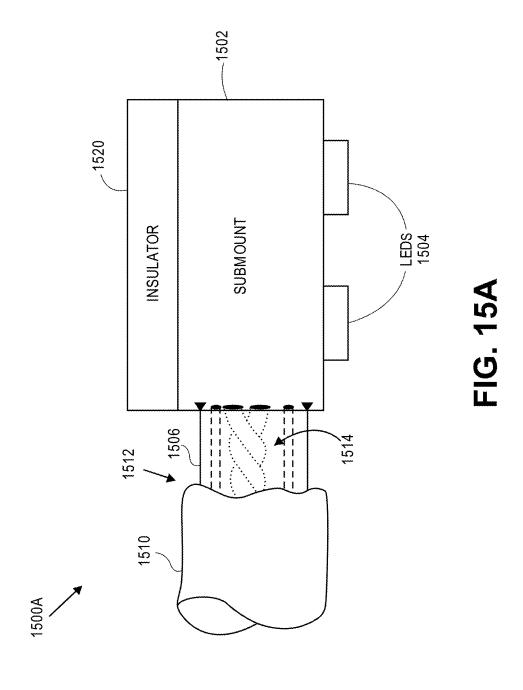
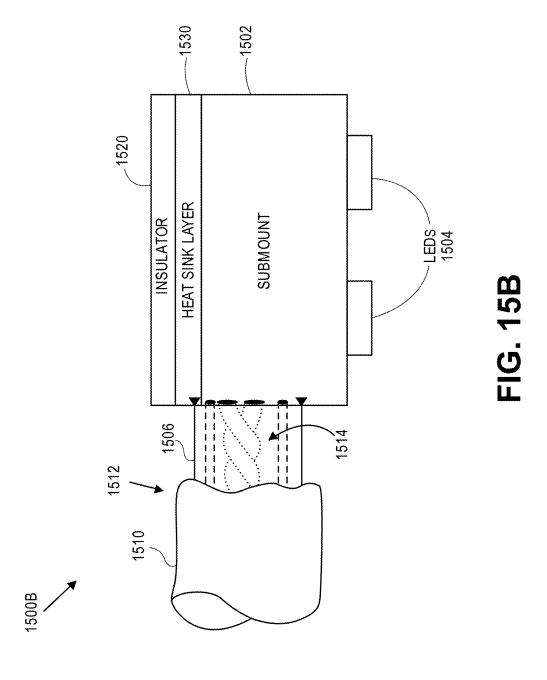


FIG. 141

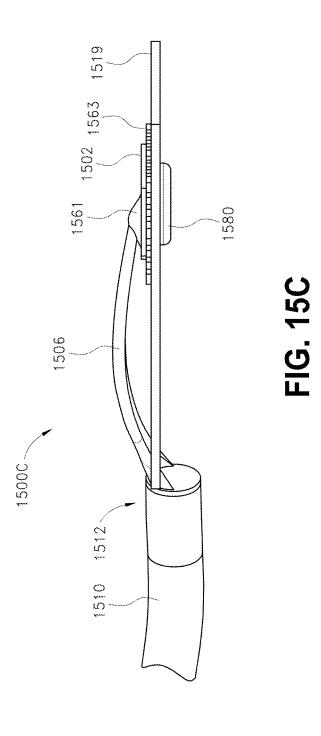
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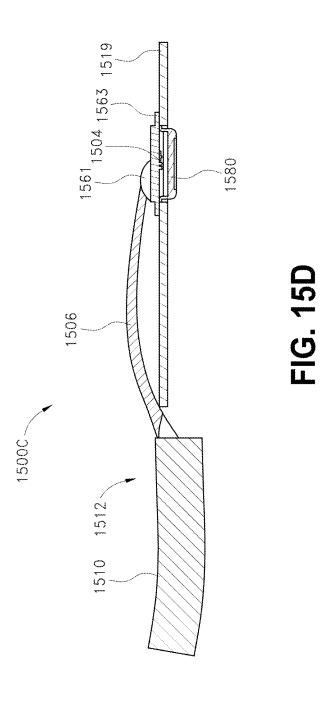
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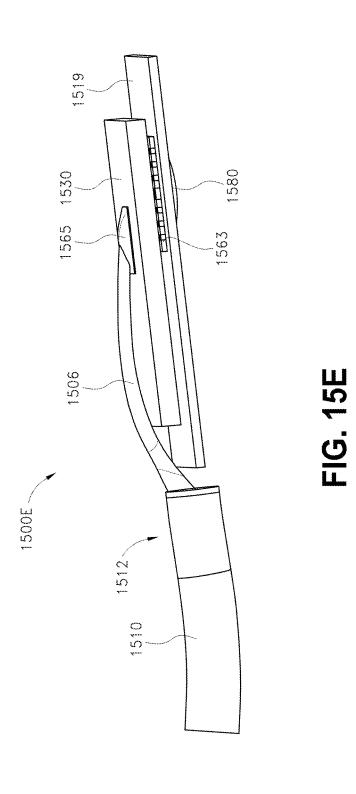
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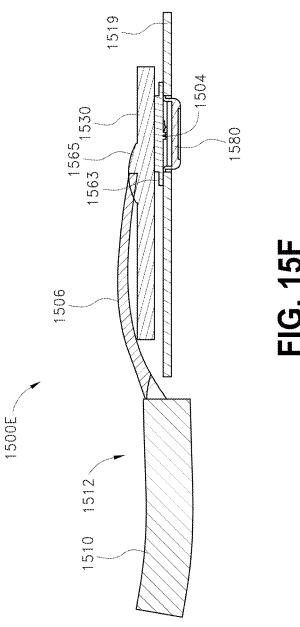


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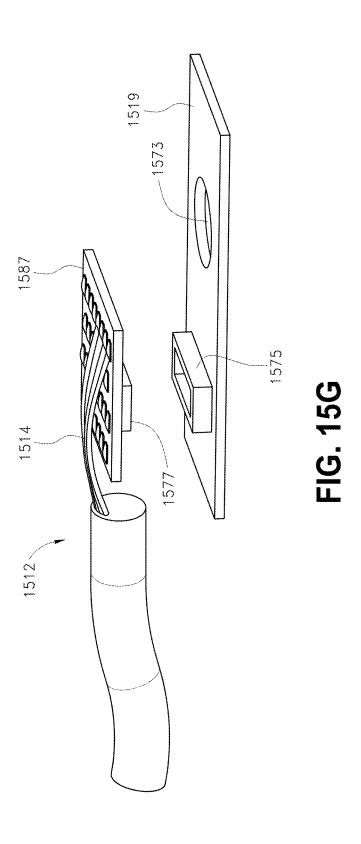


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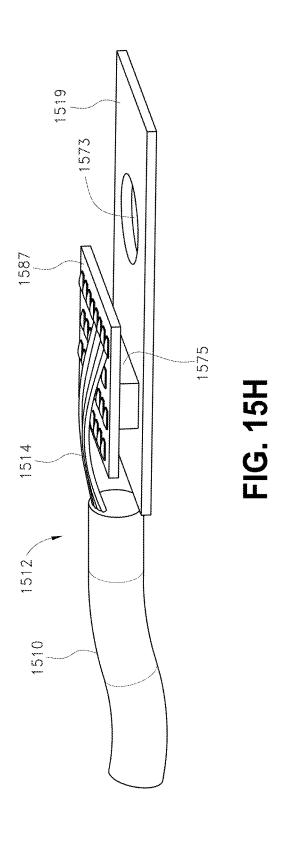


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**Patent** 

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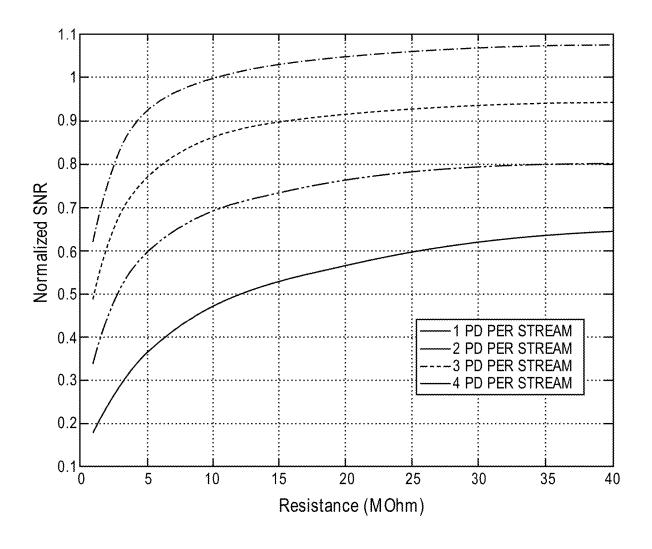
**Sheet 52 of 65** 

FIG. 151

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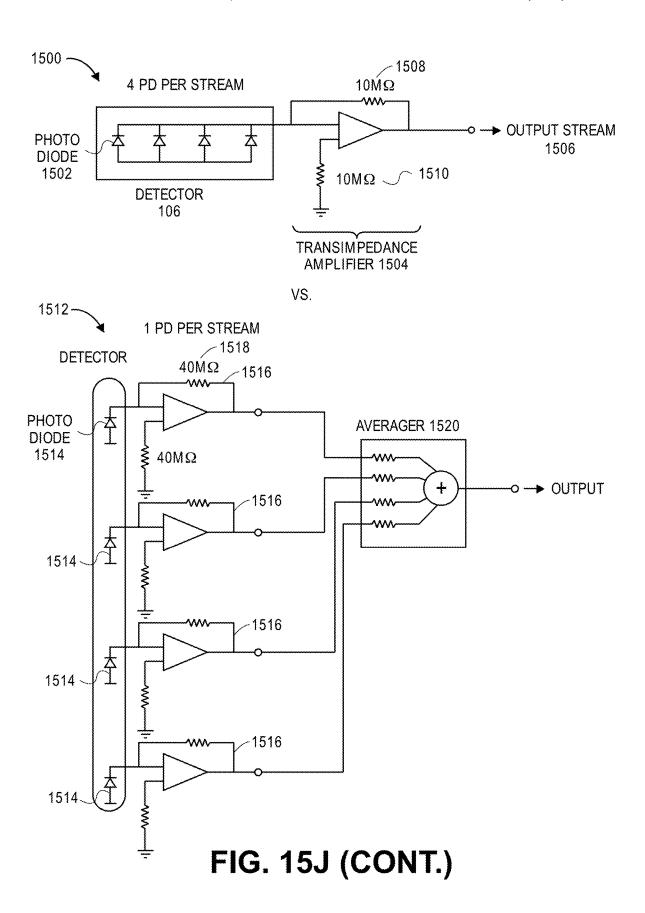
**FIG. 15J** 

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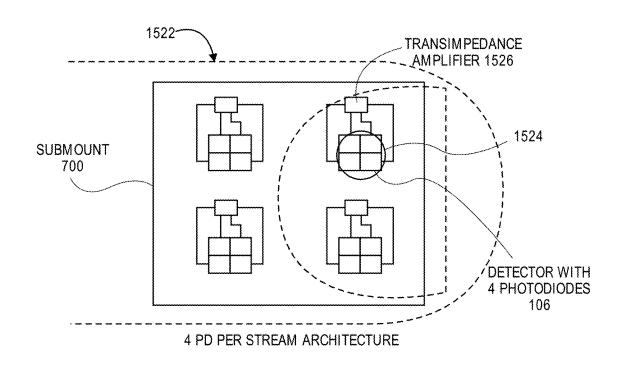
**Sheet 54 of 65** 

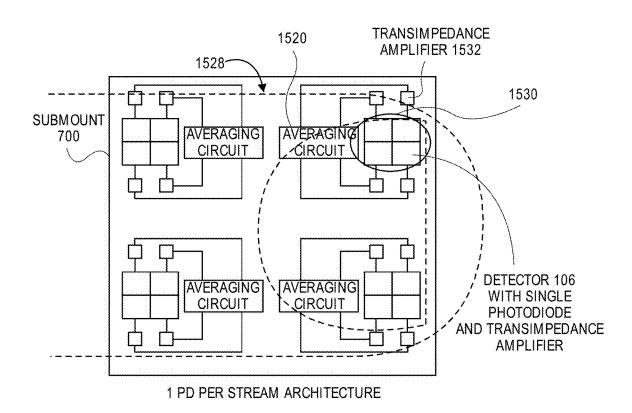


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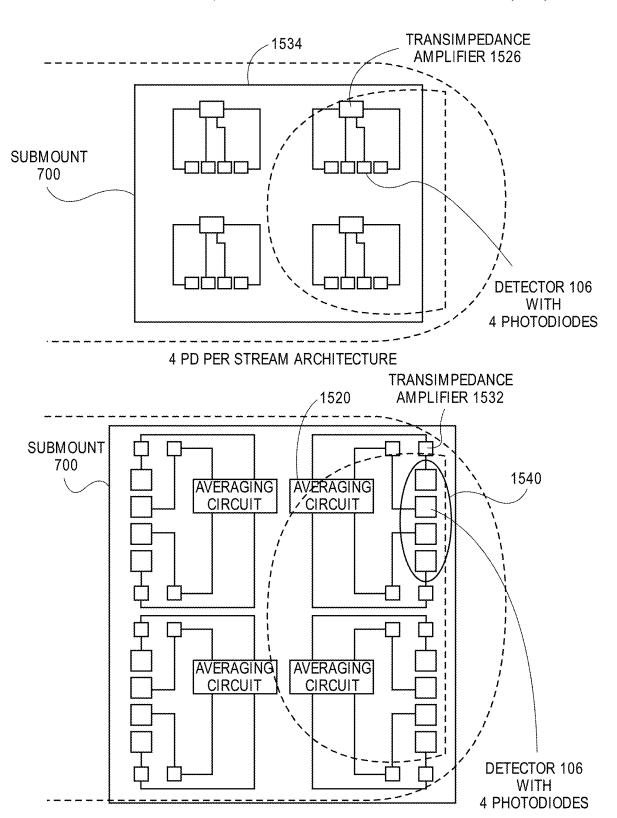
**Sheet 55 of 65** 





**FIG. 15K** 

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1 PD PER STREAM ARCHITECTURE

**FIG. 15K (CONT.)** 

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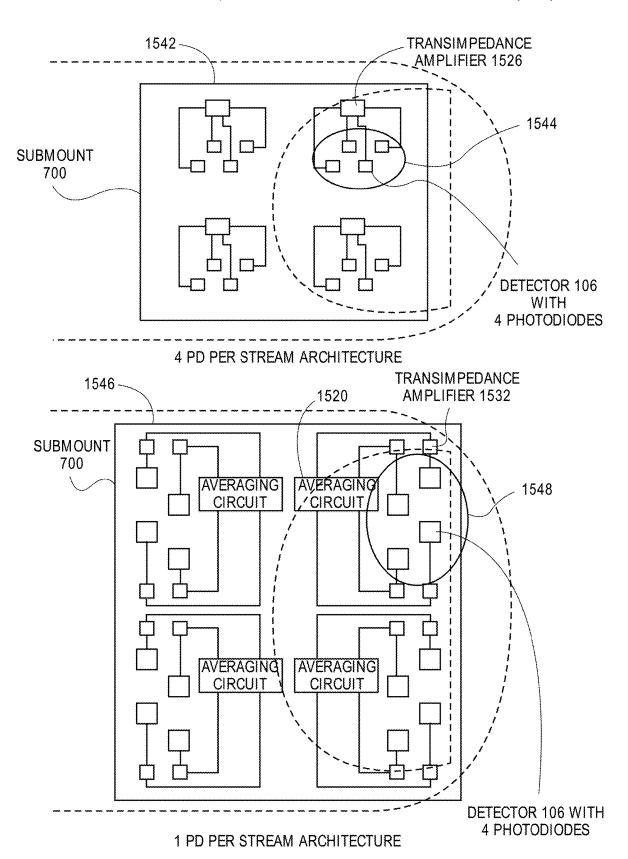


FIG. 15K (CONT.)

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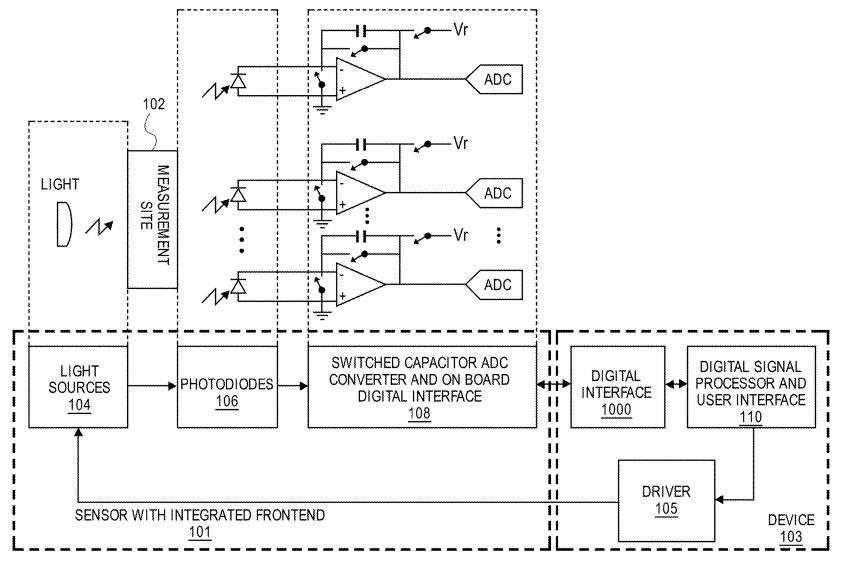
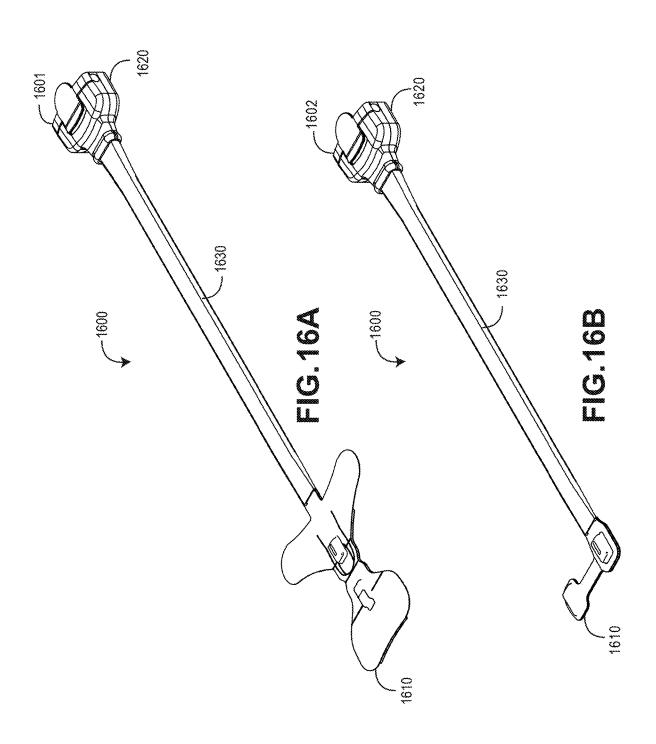
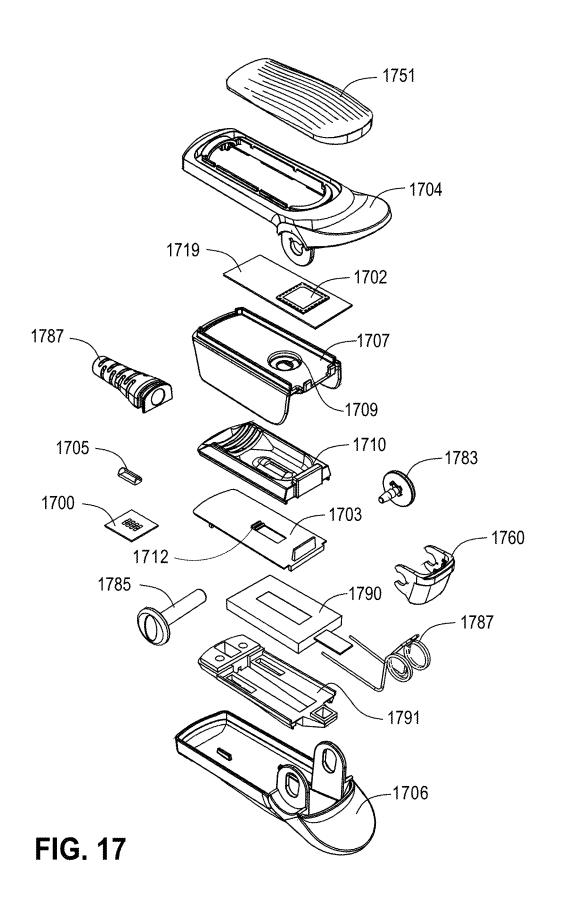


FIG. 15L

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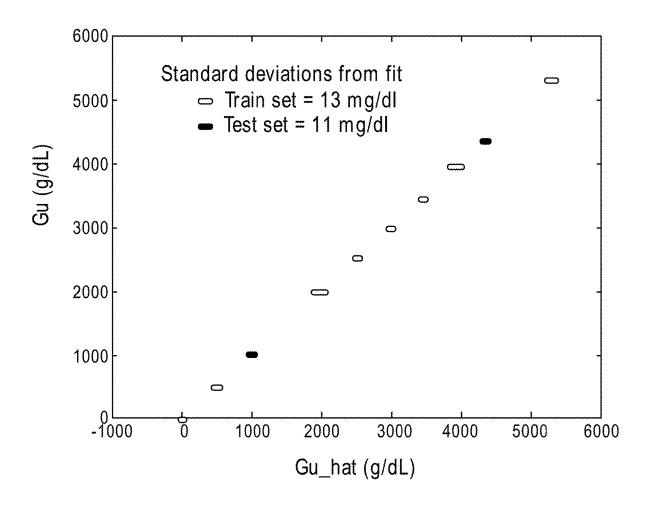


FIG. 18

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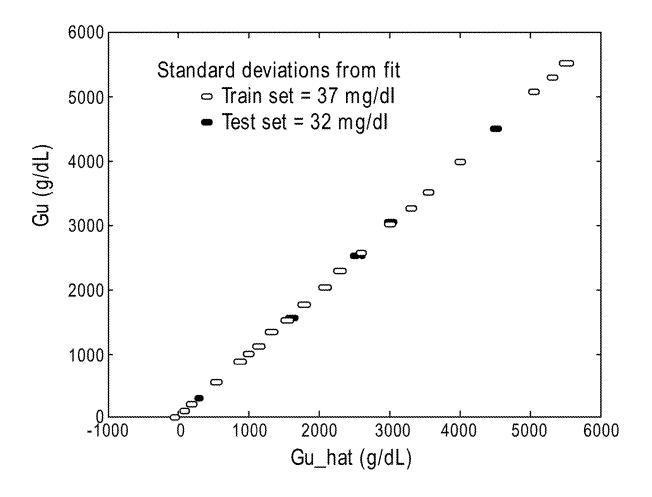


FIG. 19

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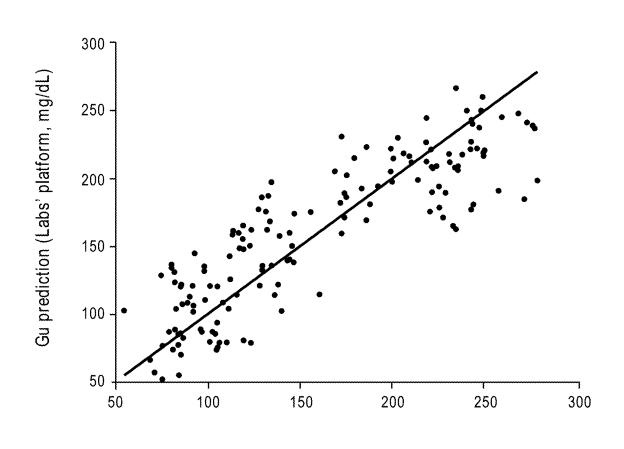


FIG. 20

Gu reference (YSI, mg/dL)

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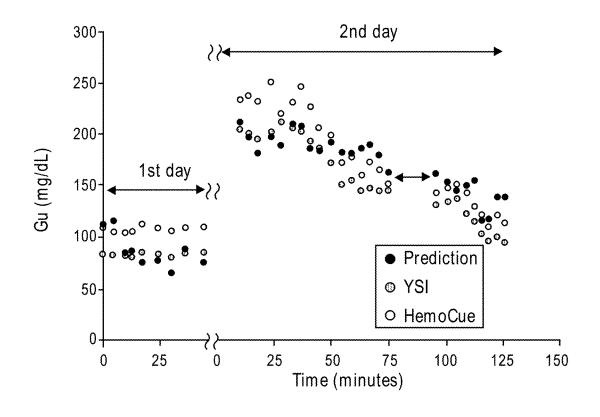


FIG. 21

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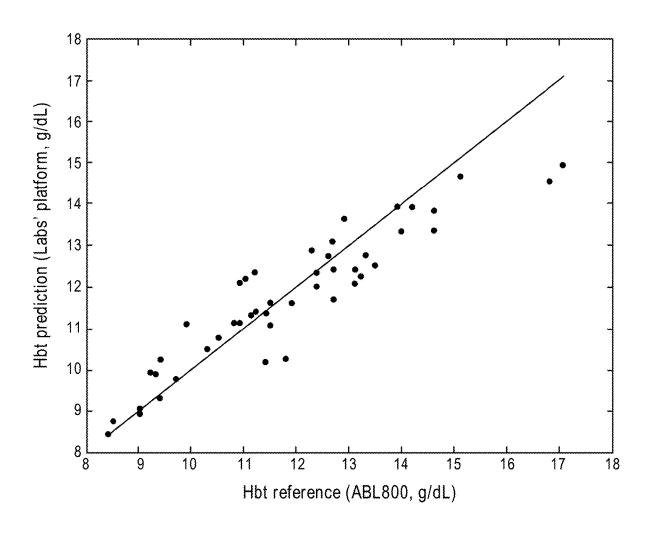


FIG. 22

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## 1

### MULTI-STREAM DATA COLLECTION SYSTEM FOR NONINVASIVE MEASUREMENT OF BLOOD CONSTITUENTS

#### RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/725,292, filed Dec. 23, 2019, which is a continuation of U.S. patent application Ser. No. 16/534,949, filed Aug. 7, 2019, which is a continuation of U.S. patent application Ser. No. 16/409,515, filed May 10, 2019, which is a continuation of U.S. patent application Ser. No. 16/261, 326, filed Jan. 29, 2019, which is a continuation of U.S. patent application Ser. No. 16/212,537, filed Dec. 6, 2018, 15 which is a continuation of U.S. patent application Ser. No. 14/981,290 filed Dec. 28, 2015, which is a continuation of U.S. patent application Ser. No. 12/829,352 filed Jul. 1, 2010, which is a continuation of U.S. patent application Ser. No. 12/534,827 filed Aug. 3, 2009, which claims the benefit 20 of priority under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/829,352 25 is also a continuation-in-part of U.S. patent application Ser. No. 12/497,528 filed Jul. 2, 2009, which claims the benefit of priority under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 30 4, 2008, 61/086,057 filed Aug. 4, 2008, 61/078,228 filed Jul.  $3,\,2008,\,61/078,\!207$  filed Jul.  $3,\,2008,\,$  and  $61/091,\!732$  filed Aug. 25, 2008. U.S. patent application Ser. No. 12/497,528 also claims the benefit of priority under 35 U.S.C. § 120 as a continuation-in-part of the following U.S. Design patent 35 application Ser. No. 29/323,409 filed Aug. 25, 2008 and Ser. No. 29/323,408 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/829,352 is also a continuation-in-part of U.S. patent application Ser. No. 12/497,523 filed Jul. 2, 2009, which claims the benefit of priority under 35 U.S.C. § 119(e) 40 of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, 61/078,228 filed Jul. 3, 2008, 61/078,207 filed Jul. 3, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent 45 application Ser. No. 12/497,523 also claims the benefit of priority under 35 U.S.C. § 120 as a continuation-in-part of the following U.S. Design patent application Ser. No. 29/323,409 filed Aug. 25, 2008 and Ser. No. 29/323,408 filed Aug. 25, 2008.

This application is related to the following U.S. Patent Applications:

application Filing Ser. No. Date	Title	Attonery Docket
12/497,528 Jul. 2, 2009	Noise Shielding for Noninvasive Device	MASCER.006A
12/497,523 Jul. 2, 2009	Contoured Protrusion for Improving Spectroscopic Measurement of Blood Constituents	MASCER.007A
12/497,506 Jul. 2, 2009	Heat Sink for Noninvasive Medical Sensor	MASCER.011A
12/534,812 Aug. 3, 2009	Multi-Stream Sensor Front Ends for Non-Invasive Measurement of Blood Constituents	MASCER.003A

# 2 -continued

application Filing Ser. No. Date	Title	Attonery Docket
12/534,823 Aug. 3, 2009	Multi-Stream Sensor for Non-Invasive Measurement of Blood Constituents	MASCER.004A
12/534,825 Aug. 3, 2009	Multi-Stream Emitter for Non-Invasive Measurement of Blood Constituents	MASCER.005A

The foregoing applications are hereby incorporated by reference in their entirety.

### BACKGROUND

The standard of care in caregiver environments includes patient monitoring through spectroscopic analysis using, for example, a pulse oximeter. Devices capable of spectroscopic analysis generally include a light source(s) transmitting optical radiation into or reflecting off a measurement site, such as, body tissue carrying pulsing blood. After attenuation by tissue and fluids of the measurement site, a photo-detection device(s) detects the attenuated light and outputs a detector signal(s) responsive to the detected attenuated light. A signal processing device(s) process the detector(s) signal(s) and outputs a measurement indicative of a blood constituent of interest, such as glucose, oxygen, met hemo-globin, total hemoglobin, other physiological parameters, or other data or combinations of data useful in determining a state or trend of wellness of a patient.

In noninvasive devices and methods, a sensor is often adapted to position a finger proximate the light source and light detector. For example, noninvasive sensors often include a clothespin-shaped housing that includes a contoured bed conforming generally to the shape of a finger.

### SUMMARY

This disclosure describes embodiments of noninvasive methods, devices, and systems for measuring a blood constituent or analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. These characteristics can relate, for example, to pulse rate, hydration, trending information and analysis, and the like

In an embodiment, the system includes a noninvasive sensor and a patient monitor communicating with the non-invasive sensor. The non-invasive sensor may include different architectures to implement some or all of the disclosed features. In addition, an artisan will recognize that the non-invasive sensor may include or may be coupled to other components, such as a network interface, and the like. Moreover, the patient monitor may include a display device, a network interface communicating with any one or combination of a computer network, a handheld computing device, a mobile phone, the Internet, or the like. In addition, embodiments may include multiple optical sources that emit light at a plurality of wavelengths and that are arranged from the perspective of the light detector(s) as a point source.

In an embodiment, a noninvasive device is capable of producing a signal responsive to light attenuated by tissue at a measurement site. The device may comprise an optical source and a plurality of photodetectors. The optical source is configured to emit optical radiation at least at wavelengths

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between about 1600 nm and about 1700 nm. The photodetectors are configured to detect the optical radiation from said optical source after attenuation by the tissue of the measurement site and each output a respective signal stream responsive to the detected optical radiation.

In an embodiment, a noninvasive, physiological sensor is capable of outputting a signal responsive to a blood analyte present in a monitored patient. The sensor may comprise a sensor housing, an optical source, and photodetectors. The optical source is positioned by the housing with respect to a 10 tissue site of a patient when said housing is applied to the patient. The photodetectors are positioned by the housing with respect to said tissue site when the housing is applied to the patient with a variation in path length among at least some of the photodetectors from the optical source. The 15 photodetectors are configured to detect a sequence of optical radiation from the optical source after attenuation by tissue of the tissue site. The photodetectors may be each configured to output a respective signal stream responsive to the detected sequence of optical radiation. An output signal 20 responsive to one or more of the signal streams is then usable to determine the blood analyte based at least in part on the variation in path length.

In an embodiment, a method of measuring an analyte based on multiple streams of optical radiation measured 25 from a measurement site is provided. A sequence of optical radiation pulses is emitted to the measurement site. At a first location, a first stream of optical radiation is detected from the measurement site. At least at one additional location different from the first location, an additional stream of 30 optical radiation is detected from the measurement site. An output measurement value indicative of the analyte is then determined based on the detected streams of optical radiation.

In various embodiments, the present disclosure relates to 35 an interface for a noninvasive sensor that comprises a front-end adapted to receive an input signals from optical detectors and provide corresponding output signals. In an embodiment, the front-end is comprised of switched-capacitor circuits that are capable of handling multiple streams of 40 signals from the optical detectors. In another embodiment, the front-end comprises transimpedance amplifiers that are capable of handling multiple streams of input signals. In addition, the transimpedance amplifiers may be configured based on the characteristics of the transimpedance amplifier 45 itself, the characteristics of the photodiodes, and the number of photodiodes coupled to the transimpedance amplifier.

In disclosed embodiments, the front-ends are employed in noninvasive sensors to assist in measuring and detecting various analytes. The disclosed noninvasive sensor may also 50 include, among other things, emitters and detectors positioned to produce multi-stream sensor information. An artisan will recognize that the noninvasive sensor may have different architectures and may include or be coupled to other components, such as a display device, a network 55 interface, and the like. An artisan will also recognize that the front-ends may be employed in any type of noninvasive sensor.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to 60 receive signals from a plurality of detectors in the sensor; a set of transimpedance amplifiers configured to convert the signals from the plurality of detectors into an output signal having a stream for each of the plurality of detectors; and an output configured to provide the output signal.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to

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receive signals from a plurality of detectors in the sensor; a set of switched capacitor circuits configured to convert the signals from the plurality of detectors into a digital output signal having a stream for each of the plurality of detectors; and an output configured to provide the digital output signal.

In an embodiment, a conversion processor for a physiological, noninvasive sensor comprises: a multi-stream input configured to receive signals from a plurality of detectors in the sensor, wherein the signals are responsive to optical radiation from a tissue site; a modulator that converts the multi-stream input into a digital bit-stream; and a signal processor that produces an output signal from the digital bit-stream.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to receive signals from a plurality of detectors in the sensor; a set of respective transimpedance amplifiers for each detector configured to convert the signals from the plurality of detectors into an output signal having a stream for each of the plurality of detectors; and an output configured to provide the output signal.

In certain embodiments, a noninvasive sensor interfaces with tissue at a measurement site and deforms the tissue in a way that increases signal gain in certain desired wavelengths.

In some embodiments, a detector for the sensor may comprise a set of photodiodes that are arranged in a spatial configuration. This spatial configuration may allow, for example, signal analysis for measuring analytes like glucose. In various embodiments, the detectors can be arranged across multiple locations in a spatial configuration. The spatial configuration provides a geometry having a diversity of path lengths among the detectors. For example, the detector in the sensor may comprise multiple detectors that are arranged to have a sufficient difference in mean path length to allow for noise cancellation and noise reduction.

In an embodiment, a physiological, noninvasive detector is configured to detect optical radiation from a tissue site. The detector comprises a set of photodetectors and a conversion processor. The set of photodetectors each provide a signal stream indicating optical radiation from the tissue site. The set of photodetectors are arranged in a spatial configuration that provides a variation in path lengths between at least some of the photodetectors. The conversion processor that provides information indicating an analyte in the tissue site based on ratios of pairs of the signal streams.

The present disclosure, according to various embodiments, relates to noninvasive methods, devices, and systems for measuring a blood analyte, such as glucose. In the present disclosure, blood analytes are measured noninvasively based on multi-stream infrared and near-infrared spectroscopy. In some embodiments, an emitter may include one or more sources that are configured as a point optical source. In addition, the emitter may be operated in a manner that allows for the measurement of an analyte like glucose. In embodiments, the emitter may comprise a plurality of LEDs that emit a sequence of pulses of optical radiation across a spectrum of wavelengths. In addition, in order to achieve the desired SNR for detecting analytes like glucose, the emitter may be driven using a progression from low power to higher power. The emitter may also have its duty cycle modified to achieve a desired SNR.

In an embodiment, a multi-stream emitter for a noninvasive, physiological device configured to transmit optical radiation in a tissue site comprises: a set of optical sources arranged as a point optical source; and a driver configured to drive the at least one light emitting diode and at least one

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optical source to transmit near-infrared optical radiation at sufficient power to measure an analyte in tissue that responds to near-infrared optical radiation.

In an embodiment, an emitter for a noninvasive, physiological device configured to transmit optical radiation in a tissue site comprises: a point optical source comprising an optical source configured to transmit infrared and near-infrared optical radiation to a tissue site; and a driver configured to drive the point optical source at a sufficient power and noise tolerance to effectively provide attenuated optical radiation from a tissue site that indicates an amount of glucose in the tissue site.

In an embodiment, a method of transmitting a stream of pulses of optical radiation in a tissue site is provided. At least one pulse of infrared optical radiation having a first pulse width is transmitted at a first power. At least one pulse of near-infrared optical radiation is transmitted at a power that is higher than the first power.

In an embodiment, a method of transmitting a stream of 20 pulses of optical radiation in a tissue site is provided. At least one pulse of infrared optical radiation having a first pulse width is transmitted at a first power. At least one pulse of near-infrared optical radiation is then transmitted, at a second power that is higher than the first power.

For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the inventions disclosed herein. Thus, the inventions disclosed herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as can be taught or suggested herein.

### BRIEF DESCRIPTION OF THE DRAWINGS

Throughout the drawings, reference numbers can be reused to indicate correspondence between referenced ele- 40 ments. The drawings are provided to illustrate embodiments of the inventions described herein and not to limit the scope thereof.

FIG. 1 illustrates a block diagram of an example data collection system capable of noninvasively measuring one 45 or more blood analytes in a monitored patient, according to an embodiment of the disclosure;

FIGS. 2A-2D illustrate an exemplary handheld monitor and an exemplary noninvasive optical sensor of the patient monitoring system of FIG. 1, according to embodiments of 50 the disclosure;

FIGS. 3A-3C illustrate side and perspective views of an exemplary noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

FIG. 3D illustrates a side view of another example noninvasive sensor housing including a heat sink, according to an embodiment of the disclosure:

FIG. 3E illustrates a perspective view of an example noninvasive sensor detector shell including example detectors, according to an embodiment of the disclosure;

FIG. 3F illustrates a side view of an example noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

FIGS. 4A through 4C illustrate top elevation, side and top 65 perspective views of an example protrusion, according to an embodiment of the disclosure;

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FIG. 5 illustrates an example graph depicting possible effects of a protrusion on light transmittance, according to an embodiment of the disclosure;

FIGS. 6A through 6D illustrate perspective, front elevation, side and top views of another example protrusion, according to an embodiment of the disclosure;

FIG. **6**E illustrates an example sensor incorporating the protrusion of FIGS. **6**A through **6**D, according to an embodiment of the disclosure;

FIGS. 7A through 7B illustrate example arrangements of conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

FIGS. 8A through 8D illustrate an example top elevation view, side views, and a bottom elevation view of the conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

FIG. 9 shows example comparative results obtained by an embodiment of a sensor;

FIGS. **10**A and **10**B illustrate comparative noise floors of various embodiments of the present disclosure;

FIG. 11A illustrates an exemplary emitter that may be employed in the sensor, according to an embodiment of the disclosure:

FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring blood constituents, according to an embodiment of the disclosure;

FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

FIG. 12A illustrates an example detector portion that may be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

FIGS. **12**B through **12**D illustrate exemplary arrangements of detectors that may be employed in an embodiment of the sensor, according to some embodiments of the disclosure;

FIGS. 12E through 12H illustrate exemplary structures of photodiodes that may be employed in embodiments of the detectors, according to some embodiments of the disclosure;

FIG. 13 illustrates an example multi-stream operation of the system of FIG. 1, according to an embodiment of the disclosure;

FIG. **14**A illustrates another example detector portion having a partially cylindrical protrusion that can be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

FIG. 14B depicts a front elevation view of the partially cylindrical protrusion of FIG. 14A;

FIGS. 14C through 14E illustrate embodiments of a 55 detector submount;

FIGS. 14F through 14H illustrate embodiment of portions of a detector shell;

FIG. **14**I illustrates a cutaway view of an embodiment of a sensor;

FIGS. 15A through 15F illustrate embodiments of sensors that include heat sink features;

FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described herein:

FIG. **15**I illustrates an exemplary architecture for a transimpedance-based front-end that may be employed in any of the sensors described herein;

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FIG. **15**J illustrates an exemplary noise model for configuring the transimpedance-based front-ends shown in FIG. **15**I.

FIG. 15K shows different architectures and layouts for various embodiments of a sensor and its detectors;

FIG. **15**L illustrates an exemplary architecture for a switched-capacitor-based front-end that may be employed in any of the sensors described herein;

FIGS. 16A and 16B illustrate embodiments of disposable optical sensors;

FIG. 17 illustrates an exploded view of certain components of an example sensor; and

FIGS. 18 through 22 illustrate various results obtained by an exemplary sensor of the disclosure.

### DETAILED DESCRIPTION

The present disclosure generally relates to non-invasive medical devices. In the present disclosure, a sensor can measure various blood constituents or analytes noninvasively using multi-stream spectroscopy. In an embodiment, the multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes or percentages thereof (e.g., saturation) based on various 25 combinations of features and components.

In various embodiments, the present disclosure relates to an interface for a noninvasive glucose sensor that comprises a front-end adapted to receive an input signals from optical detectors and provide corresponding output signals. The 30 front-end may comprise, among other things, switched capacitor circuits or transimpedance amplifiers. In an embodiment, the front-end may comprise switched capacitor circuits that are configured to convert the output of sensor's detectors into a digital signal. In another embodiment, the 35 front-end may comprise transimpedance amplifiers. These transimpedance amplifiers may be configured to match one or more photodiodes in a detector based on a noise model that accounts for characteristics, such as the impedance, of the transimpedance amplifier, characteristics of each photo- 40 diode, such as the impedance, and the number of photodiodes coupled to the transimpedance amplifier.

In the present disclosure, the front-ends are employed in a sensor that measures various blood analytes noninvasively using multi-stream spectroscopy. In an embodiment, the 45 multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes, such as glucose, total hemoglobin, methemoglobin, oxygen content, and the like, based on various combinations of features and 50 components.

In an embodiment, a physiological sensor includes a detector housing that can be coupled to a measurement site, such as a patient's finger. The sensor housing can include a curved bed that can generally conform to the shape of the 55 measurement site. In addition, the curved bed can include a protrusion shaped to increase an amount of light radiation from the measurement site. In an embodiment, the protrusion is used to thin out the measurement site. This allows the light radiation to pass through less tissue, and accordingly is 60 attenuated less. In an embodiment, the protrusion can be used to increase the area from which attenuated light can be measured. In an embodiment, this is done through the use of a lens which collects attenuated light exiting the measurement site and focuses onto one or more detectors. The 65 protrusion can advantageously include plastic, including a hard opaque plastic, such as a black or other colored plastic,

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helpful in reducing light noise. In an embodiment, such light noise includes light that would otherwise be detected at a photodetector that has not been attenuated by tissue of the measurement site of a patient sufficient to cause the light to adequately included information indicative of one or more physiological parameters of the patient. Such light noise includes light piping.

In an embodiment, the protrusion can be formed from the curved bed, or can be a separate component that is positionable with respect to the bed. In an embodiment, a lens made from any appropriate material is used as the protrusion. The protrusion can be convex in shape. The protrusion can also be sized and shaped to conform the measurement site into a flat or relatively flat surface. The protrusion can also be sized to conform the measurement site into a rounded surface, such as, for example, a concave or convex surface. The protrusion can include a cylindrical or partially cylindrical shape. The protrusion can be sized or shaped differently for different types of patients, such as an adult, child, or infant. The protrusion can also be sized or shaped differently for different measurement sites, including, for example, a finger, toe, hand, foot, ear, forehead, or the like. The protrusion can thus be helpful in any type of noninvasive sensor. The external surface of the protrusion can include one or more openings or windows. The openings can be made from glass to allow attenuated light from a measurement site, such as a finger, to pass through to one or more detectors. Alternatively, some of all of the protrusion can be a lens, such as a partially cylindrical lens.

The sensor can also include a shielding, such as a metal enclosure as described below or embedded within the protrusion to reduce noise. The shielding can be constructed from a conductive material, such as copper, in the form of a metal cage or enclosure, such as a box. The shielding can include a second set of one or more openings or windows. The second set of openings can be made from glass and allow light that has passed through the first set of windows of the external surface of the protrusion to pass through to one or more detectors that can be enclosed, for example, as described below.

In various embodiments, the shielding can include any substantially transparent, conductive material placed in the optical path between an emitter and a detector. The shielding can be constructed from a transparent material, such as glass, plastic, and the like. The shielding can have an electrically conductive material or coating that is at least partially transparent. The electrically conductive coating can be located on one or both sides of the shielding, or within the body of the shielding. In addition, the electrically conductive coating can be uniformly spread over the shielding or may be patterned. Furthermore, the coating can have a uniform or varying thickness to increase or optimize its shielding effect. The shielding can be helpful in virtually any type of non-invasive sensor that employs spectroscopy.

In an embodiment, the sensor can also include a heat sink. In an embodiment, the heat sink can include a shape that is functional in its ability to dissipate excess heat and aesthetically pleasing to the wearer. For example, the heat sink can be configured in a shape that maximizes surface area to allow for greater dissipation of heat. In an embodiment, the heat sink includes a metalicized plastic, such as plastic including carbon and aluminum to allow for improved thermal conductivity and diffusivity. In an embodiment, the heat sink can advantageously be inexpensively molded into desired shapes and configurations for aesthetic and functional purposes. For example, the shape of the heat sink can

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be a generally curved surface and include one or more fins, undulations, grooves or channels, or combs.

The sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter can include a plurality of sets of optical sources that, 5 in an embodiment, are arranged together as a point source. The various optical sources can emit a sequence of optical radiation pulses at different wavelengths towards a measurement site, such as a patient's finger. Detectors can then detect optical radiation from the measurement site. The 10 optical sources and optical radiation detectors can operate at any appropriate wavelength, including, as discussed herein, infrared, near infrared, visible light, and ultraviolet. In addition, the optical sources and optical radiation detectors can operate at any appropriate wavelength, and such modifications to the embodiments desirable to operate at any such wavelength will be apparent to those skilled in the art.

In certain embodiments, multiple detectors are employed and arranged in a spatial geometry. This spatial geometry provides a diversity of path lengths among at least some of 20 the detectors and allows for multiple bulk and pulsatile measurements that are robust. Each of the detectors can provide a respective output stream based on the detected optical radiation, or a sum of output streams can be provided from multiple detectors. In some embodiments, the sensor 25 can also include other components, such as one or more heat sinks and one or more thermistors.

The spatial configuration of the detectors provides a geometry having a diversity of path lengths among the detectors. For example, a detector in the sensor may comprise multiple detectors that are arranged to have a sufficient difference in mean path length to allow for noise cancellation and noise reduction. In addition, walls may be used to separate individual photodetectors and prevent mixing of detected optical radiation between the different locations on 35 the measurement site. A window may also be employed to facilitate the passing of optical radiation at various wavelengths for measuring glucose in the tissue.

In the present disclosure, a sensor may measure various blood constituents or analytes noninvasively using spectroscopy and a recipe of various features. As disclosed herein, the sensor is capable of non-invasively measuring blood analytes, such as, glucose, total hemoglobin, methemoglobin, oxygen content, and the like. In an embodiment, the spectroscopy used in the sensor can employ visible, infrared 45 and near infrared wavelengths. The sensor may comprise an emitter, a detector, and other components. In some embodiments, the sensor may also comprise other components, such as one or more heat sinks and one or more thermistors.

In various embodiments, the sensor may also be coupled 50 to one or more companion devices that process and/or display the sensor's output. The companion devices may comprise various components, such as a sensor front-end, a signal processor, a display, a network interface, a storage device or memory, etc. 55

A sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter is configured as a point optical source that comprises a plurality of LEDs that emit a sequence of pulses of optical radiation across a spectrum of wavelengths. In some 60 embodiments, the plurality of sets of optical sources may each comprise at least one top-emitting LED and at least one super luminescent LED. In some embodiments, the emitter comprises optical sources that transmit optical radiation in the infrared or near-infrared wavelengths suitable for detecting blood analytes like glucose. In order to achieve the desired SNR for detecting analytes like glucose, the emitter

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may be driven using a progression from low power to higher power. In addition, the emitter may have its duty cycle modified to achieve a desired SNR.

The emitter may be constructed of materials, such as aluminum nitride and may include a heat sink to assist in heat dissipation. A thermistor may also be employed to account for heating effects on the LEDs. The emitter may further comprise a glass window and a nitrogen environment to improve transmission from the sources and prevent oxidative effects.

The sensor can be coupled to one or more monitors that process and/or display the sensor's output. The monitors can include various components, such as a sensor front end, a signal processor, a display, etc.

The sensor can be integrated with a monitor, for example, into a handheld unit including the sensor, a display and user controls. In other embodiments, the sensor can communicate with one or more processing devices. The communication can be via wire(s), cable(s), flex circuit(s), wireless technologies, or other suitable analog or digital communication methodologies and devices to perform those methodologies. Many of the foregoing arrangements allow the sensor to be attached to the measurement site while the device is attached elsewhere on a patient, such as the patient's arm, or placed at a location near the patient, such as a bed, shelf or table. The sensor or monitor can also provide outputs to a storage device or network interface.

Reference will now be made to the Figures to discuss embodiments of the present disclosure.

FIG. 1 illustrates an example of a data collection system 100. In certain embodiments, the data collection system 100 noninvasively measure a blood analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. The system 100 can also measure additional blood analytes and/or other physiological parameters useful in determining a state or trend of wellness of a patient.

The data collection system 100 can be capable of measuring optical radiation from the measurement site. For example, in some embodiments, the data collection system 100 can employ photodiodes defined in terms of area. In an embodiment, the area is from about 1 mm²-5 mm² (or higher) that are capable of detecting about 100 nanoamps (nA) or less of current resulting from measured light at full scale. In addition to having its ordinary meaning, the phrase "at full scale" can mean light saturation of a photodiode amplifier (not shown). Of course, as would be understood by a person of skill in the art from the present disclosure, various other sizes and types of photodiodes can be used with the embodiments of the present disclosure.

The data collection system 100 can measure a range of approximately about 2 nA to about 100 nA full scale. The data collection system 100 can also include sensor frontends that are capable of processing and amplifying current from the detector(s) at signal-to-noise ratios (SNRs) of about 100 decibels (dB) or more, such as about 120 dB in order to measure various desired analytes. The data collection system 100 can operate with a lower SNR if less accuracy is desired for an analyte like glucose.

The data collection system 100 can measure analyte concentrations, including glucose, at least in part by detecting light attenuated by a measurement site 102. The measurement site 102 can be any location on a patient's body, such as a finger, foot, ear lobe, or the like. For convenience, this disclosure is described primarily in the context of a

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finger measurement site 102. However, the features of the embodiments disclosed herein can be used with other measurement sites 102.

In the depicted embodiment, the system 100 includes an optional tissue thickness adjuster or tissue shaper 105, which 5 can include one or more protrusions, bumps, lenses, or other suitable tissue-shaping mechanisms. In certain embodiments, the tissue shaper 105 is a flat or substantially flat surface that can be positioned proximate the measurement site 102 and that can apply sufficient pressure to cause the 10 tissue of the measurement site 102 to be flat or substantially flat. In other embodiments, the tissue shaper 105 is a convex or substantially convex surface with respect to the measurement site 102. Many other configurations of the tissue shaper 105 are possible. Advantageously, in certain embodiments, 15 the tissue shaper 105 reduces thickness of the measurement site 102 while preventing or reducing occlusion at the measurement site 102. Reducing thickness of the site can advantageously reduce the amount of attenuation of the light because there is less tissue through which the light must 20 travel. Shaping the tissue in to a convex (or alternatively concave) surface can also provide more surface area from which light can be detected.

The embodiment of the data collection system 100 shown also includes an optional noise shield 103. In an embodi- 25 ment, the noise shield 103 can be advantageously adapted to reduce electromagnetic noise while increasing the transmittance of light from the measurement site 102 to one or more detectors 106 (described below). For example, the noise shield 103 can advantageously include a conductive coated 30 glass or metal grid electrically communicating with one or more other shields of the sensor 101 or electrically grounded. In an embodiment where the noise shield 103 includes conductive coated glass, the coating can advantageously include indium tin oxide. In an embodiment, the 35 indium tin oxide includes a surface resistivity ranging from approximately 30 ohms per square inch to about 500 ohms per square inch. In an embodiment, the resistivity is approximately 30, 200, or 500 ohms per square inch. As would be understood by a person of skill in the art from the present 40 disclosure, other resistivities can also be used which are less than about 30 ohms or more than about 500 ohms. Other conductive materials transparent or substantially transparent to light can be used instead.

In some embodiments, the measurement site **102** is 45 located somewhere along a non-dominant arm or a non-dominant hand, e.g., a right-handed person's left arm or left hand. In some patients, the non-dominant arm or hand can have less musculature and higher fat content, which can result in less water content in that tissue of the patient. Tissue 50 having less water content can provide less interference with the particular wavelengths that are absorbed in a useful manner by blood analytes like glucose. Accordingly, in some embodiments, the data collection system **100** can be used on a person's non-dominant hand or arm.

The data collection system 100 can include a sensor 101 (or multiple sensors) that is coupled to a processing device or physiological monitor 109. In an embodiment, the sensor 101 and the monitor 109 are integrated together into a single unit. In another embodiment, the sensor 101 and the monitor 60 109 are separate from each other and communicate one with another in any suitable manner, such as via a wired or wireless connection. The sensor 101 and monitor 109 can be attachable and detachable from each other for the convenience of the user or caregiver, for ease of storage, sterility 65 issues, or the like. The sensor 101 and the monitor 109 will now be further described.

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In the depicted embodiment shown in FIG. 1, the sensor 101 includes an emitter 104, a tissue shaper 105, a set of detectors 106, and a front-end interface 108. The emitter 104 can serve as the source of optical radiation transmitted towards measurement site 102. As will be described in further detail below, the emitter 104 can include one or more sources of optical radiation, such as LEDs, laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter 104 includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation.

In some embodiments, the emitter **104** is used as a point optical source, and thus, the one or more optical sources of the emitter **104** can be located within a close distance to each other, such as within about a 2 mm to about 4 mm. The emitters **104** can be arranged in an array, such as is described in U.S. Publication No. 2006/0211924, filed Sep. 21, 2006, titled "Multiple Wavelength Sensor Emitters," the disclosure of which is hereby incorporated by reference in its entirety. In particular, the emitters **104** can be arranged at least in part as described in paragraphs [0061] through [0068] of the aforementioned publication, which paragraphs are hereby incorporated specifically by reference. Other relative spatial relationships can be used to arrange the emitters **104**.

For analytes like glucose, currently available non-invasive techniques often attempt to employ light near the water absorbance minima at or about 1600 nm. Typically, these devices and methods employ a single wavelength or single band of wavelengths at or about 1600 nm. However, to date, these techniques have been unable to adequately consistently measure analytes like glucose based on spectroscopy.

In contrast, the emitter 104 of the data collection system 100 can emit, in certain embodiments, combinations of optical radiation in various bands of interest. For example, in some embodiments, for analytes like glucose, the emitter 104 can emit optical radiation at three (3) or more wavelengths between about 1600 nm to about 1700 nm. In particular, the emitter 104 can emit optical radiation at or about 1610 nm, about 1640 nm, and about 1665 nm. In some circumstances, the use of three wavelengths within about 1600 nm to about 1700 nm enable sufficient SNRs of about 100 dB, which can result in a measurement accuracy of about 20 mg/dL or better for analytes like glucose.

In other embodiments, the emitter 104 can use two (2) wavelengths within about 1600 nm to about 1700 nm to advantageously enable SNRs of about 85 dB, which can result in a measurement accuracy of about 25-30 mg/dL or better for analytes like glucose. Furthermore, in some embodiments, the emitter 104 can emit light at wavelengths above about 1670 nm. Measurements at these wavelengths can be advantageously used to compensate or confirm the contribution of protein, water, and other non-hemoglobin species exhibited in measurements for analytes like glucose conducted between about 1600 nm and about 1700 nm. Of course, other wavelengths and combinations of wavelengths can be used to measure analytes and/or to distinguish other types of tissue, fluids, tissue properties, fluid properties, combinations of the same or the like.

For example, the emitter 104 can emit optical radiation across other spectra for other analytes. In particular, the emitter 104 can employ light wavelengths to measure various blood analytes or percentages (e.g., saturation) thereof. For example, in one embodiment, the emitter 104 can emit optical radiation in the form of pulses at wavelengths about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about

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1665 nm. In another embodiment, the emitter **104** can emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of 5 course, the emitter **104** can transmit any of a variety of wavelengths of visible or near-infrared optical radiation.

Due to the different responses of analytes to the different wavelengths, certain embodiments of the data collection system 100 can advantageously use the measurements at 10 these different wavelengths to improve the accuracy of measurements. For example, the measurements of water from visible and infrared light can be used to compensate for water absorbance that is exhibited in the near-infrared wavelengths.

As briefly described above, the emitter **104** can include sets of light-emitting diodes (LEDs) as its optical source. The emitter **104** can use one or more top-emitting LEDs. In particular, in some embodiments, the emitter **104** can include top-emitting LEDs emitting light at about 850 nm to 20 1350 nm.

The emitter 104 can also use super luminescent LEDs (SLEDs) or side-emitting LEDs. In some embodiments, the emitter 104 can employ SLEDs or side-emitting LEDs to emit optical radiation at about 1600 nm to about 1800 nm. 25 Emitter 104 can use SLEDs or side-emitting LEDs to transmit near infrared optical radiation because these types of sources can transmit at high power or relatively high power, e.g., about 40 mW to about 100 mW. This higher power capability can be useful to compensate or overcome 30 the greater attenuation of these wavelengths of light in tissue and water. For example, the higher power emission can effectively compensate and/or normalize the absorption signal for light in the mentioned wavelengths to be similar in amplitude and/or effect as other wavelengths that can be 35 detected by one or more photodetectors after absorption. However, the embodiments of the present disclosure do not necessarily require the use of high power optical sources. For example, some embodiments may be configured to measure analytes, such as total hemoglobin (tHb), oxygen 40 saturation (SpO<sub>2</sub>), carboxyhemoglobin, methemoglobin, etc., without the use of high power optical sources like side emitting LEDs. Instead, such embodiments may employ other types of optical sources, such as top emitting LEDs. Alternatively, the emitter **104** can use other types of sources 45 of optical radiation, such as a laser diode, to emit nearinfrared light into the measurement site 102.

In addition, in some embodiments, in order to assist in achieving a comparative balance of desired power output between the LEDs, some of the LEDs in the emitter 104 can 50 have a filter or covering that reduces and/or cleans the optical radiation from particular LEDs or groups of LEDs. For example, since some wavelengths of light can penetrate through tissue relatively well, LEDs, such as some or all of the top-emitting LEDs can use a filter or covering, such as 55 a cap or painted dye. This can be useful in allowing the emitter 104 to use LEDs with a higher output and/or to equalize intensity of LEDs.

The data collection system 100 also includes a driver 111 that drives the emitter 104. The driver 111 can be a circuit 60 or the like that is controlled by the monitor 109. For example, the driver 111 can provide pulses of current to the emitter 104. In an embodiment, the driver 111 drives the emitter 104 in a progressive fashion, such as in an alternating manner. The driver 111 can drive the emitter 104 with a 65 series of pulses of about 1 milliwatt (mW) for some wavelengths that can penetrate tissue relatively well and from

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about 40 mW to about 100 mW for other wavelengths that tend to be significantly absorbed in tissue. A wide variety of other driving powers and driving methodologies can be used in various embodiments.

The driver 111 can be synchronized with other parts of the sensor 101 and can minimize or reduce jitter in the timing of pulses of optical radiation emitted from the emitter 104. In some embodiments, the driver 111 is capable of driving the emitter 104 to emit optical radiation in a pattern that varies by less than about 10 parts-per-million.

The detectors 106 capture and measure light from the measurement site 102. For example, the detectors 106 can capture and measure light transmitted from the emitter 104 that has been attenuated or reflected from the tissue in the measurement site 102. The detectors 106 can output a detector signal 107 responsive to the light captured or measured. The detectors 106 can be implemented using one or more photodiodes, phototransistors, or the like.

In addition, the detectors 106 can be arranged with a spatial configuration to provide a variation of path lengths among at least some of the detectors 106. That is, some of the detectors 106 can have the substantially, or from the perspective of the processing algorithm, effectively, the same path length from the emitter 104. However, according to an embodiment, at least some of the detectors 106 can have a different path length from the emitter 104 relative to other of the detectors 106. Variations in path lengths can be helpful in allowing the use of a bulk signal stream from the detectors 106. In some embodiments, the detectors 106 may employ a linear spacing, a logarithmic spacing, or a two or three dimensional matrix of spacing, or any other spacing scheme in order to provide an appropriate variation in path lengths.

The front end interface 108 provides an interface that adapts the output of the detectors 106, which is responsive to desired physiological parameters. For example, the front end interface 108 can adapt a signal 107 received from one or more of the detectors 106 into a form that can be processed by the monitor 109, for example, by a signal processor 110 in the monitor 109. The front end interface 108 can have its components assembled in the sensor 101, in the monitor 109, in connecting cabling (if used), combinations of the same, or the like. The location of the front end interface 108 can be chosen based on various factors including space desired for components, desired noise reductions or limits, desired heat reductions or limits, and the like.

The front end interface 108 can be coupled to the detectors 106 and to the signal processor 110 using a bus, wire, electrical or optical cable, flex circuit, or some other form of signal connection. The front end interface 108 can also be at least partially integrated with various components, such as the detectors 106. For example, the front end interface 108 can include one or more integrated circuits that are on the same circuit board as the detectors 106. Other configurations can also be used.

The front end interface 108 can be implemented using one or more amplifiers, such as transimpedance amplifiers, that are coupled to one or more analog to digital converters (ADCs) (which can be in the monitor 109), such as a sigma-delta ADC. A transimpedance-based front end interface 108 can employ single-ended circuitry, differential circuitry, and/or a hybrid configuration. A transimpedance-based front end interface 108 can be useful for its sampling rate capability and freedom in modulation/demodulation algorithms. For example, this type of front end interface 108

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can advantageously facilitate the sampling of the ADCs being synchronized with the pulses emitted from the emitter 104.

The ADC or ADCs can provide one or more outputs into multiple channels of digital information for processing by the signal processor 110 of the monitor 109. Each channel can correspond to a signal output from a detector 106.

In some embodiments, a programmable gain amplifier (PGA) can be used in combination with a transimpedance-based front end interface 108. For example, the output of a transimpedance-based front end interface 108 can be output to a PGA that is coupled with an ADC in the monitor 109. A PGA can be useful in order to provide another level of amplification and control of the stream of signals from the detectors 106. Alternatively, the PGA and ADC components can be integrated with the transimpedance-based front end interface 108 in the sensor 101.

In another embodiment, the front end interface 108 can be implemented using switched-capacitor circuits. A switched-capacitor-based front end interface 108 can be useful for, in certain embodiments, its resistor-free design and analog averaging properties. In addition, a switched-capacitor-based front end interface 108 can be useful because it can provide a digital signal to the signal processor 110 in the 25 monitor 109.

As shown in FIG. 1, the monitor 109 can include the signal processor 110 and a user interface, such as a display 112. The monitor 109 can also include optional outputs alone or in combination with the display 112, such as a 30 storage device 114 and a network interface 116. In an embodiment, the signal processor 110 includes processing logic that determines measurements for desired analytes, such as glucose, based on the signals received from the detectors 106. The signal processor 110 can be implemented 35 using one or more microprocessors or subprocessors (e.g., cores), digital signal processors, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), combinations of the same, and the like.

The signal processor 110 can provide various signals that 40 control the operation of the sensor 101. For example, the signal processor 110 can provide an emitter control signal to the driver 111. This control signal can be useful in order to synchronize, minimize, or reduce jitter in the timing of pulses emitted from the emitter 104. Accordingly, this 45 control signal can be useful in order to cause optical radiation pulses emitted from the emitter 104 to follow a precise timing and consistent pattern. For example, when a transimpedance-based front end interface 108 is used, the control signal from the signal processor 110 can provide synchro- 50 nization with the ADC in order to avoid aliasing, cross-talk, and the like. As also shown, an optional memory 113 can be included in the front-end interface 108 and/or in the signal processor 110. This memory 113 can serve as a buffer or storage location for the front-end interface 108 and/or the 55 signal processor 110, among other uses.

The user interface 112 can provide an output, e.g., on a display, for presentation to a user of the data collection system 100. The user interface 112 can be implemented as a touch-screen display, an LCD display, an organic LED 60 display, or the like. In addition, the user interface 112 can be manipulated to allow for measurement on the non-dominant side of patient. For example, the user interface 112 can include a flip screen, a screen that can be moved from one side to another on the monitor 109, or can include an ability 65 to reorient its display indicia responsive to user input or device orientation. In alternative embodiments, the data

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collection system 100 can be provided without a user interface 112 and can simply provide an output signal to a separate display or system.

A storage device 114 and a network interface 116 represent other optional output connections that can be included in the monitor 109. The storage device 114 can include any computer-readable medium, such as a memory device, hard disk storage, EEPROM, flash drive, or the like. The various software and/or firmware applications can be stored in the storage device 114, which can be executed by the signal processor 110 or another processor of the monitor 109. The network interface 116 can be a serial bus port (RS-232/RS-485), a Universal Serial Bus (USB) port, an Ethernet port, a wireless interface (e.g., WiFi such as any 802.1x interface, including an internal wireless card), or other suitable communication device(s) that allows the monitor 109 to communicate and share data with other devices. The monitor 109 can also include various other components not shown, such as a microprocessor, graphics processor, or controller to output the user interface 112, to control data communications, to compute data trending, or to perform other opera-

Although not shown in the depicted embodiment, the data collection system 100 can include various other components or can be configured in different ways. For example, the sensor 101 can have both the emitter 104 and detectors 106 on the same side of the measurement site 102 and use reflectance to measure analytes. The data collection system 100 can also include a sensor that measures the power of light emitted from the emitter 104.

FIGS. 2A through 2D illustrate example monitoring devices 200 in which the data collection system 100 can be housed. Advantageously, in certain embodiments, some or all of the example monitoring devices 200 shown can have a shape and size that allows a user to operate it with a single hand or attach it, for example, to a patient's body or limb. Although several examples are shown, many other monitoring device configurations can be used to house the data collection system 100. In addition, certain of the features of the monitoring devices 200 shown in FIGS. 2A through 2D can be combined with features of the other monitoring devices 200 shown.

Referring specifically to FIG. 2A, an example monitoring device 200A is shown, in which a sensor 201a and a monitor 209a are integrated into a single unit. The monitoring device 200A shown is a handheld or portable device that can measure glucose and other analytes in a patient's finger. The sensor 201a includes an emitter shell 204a and a detector shell 206a. The depicted embodiment of the monitoring device 200A also includes various control buttons 208a and a display 210a.

The sensor 201a can be constructed of white material used for reflective purposes (such as white silicone or plastic), which can increase the usable signal at the detector 106 by forcing light back into the sensor 201a. Pads in the emitter shell 204a and the detector shell 206a can contain separated windows to prevent or reduce mixing of light signals, for example, from distinct quadrants on a patient's finger. In addition, these pads can be made of a relatively soft material, such as a gel or foam, in order to conform to the shape, for example, of a patient's finger. The emitter shell 204a and the detector shell 206a can also include absorbing black or grey material portions to prevent or reduce ambient light from entering into the sensor 201a.

In some embodiments, some or all portions of the emitter shell **204***a* and/or detector shell **206***a* can be detachable and/or disposable. For example, some or all portions of the

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shells 204a and 206a can be removable pieces. The removability of the shells 204a and 206a can be useful for sanitary purposes or for sizing the sensor 201a to different patients. The monitor 209a can include a fitting, slot, magnet, or other connecting mechanism to allow the sensor 201c to be 5 removably attached to the monitor 209a.

The monitoring device 200a also includes optional control buttons 208a and a display 210a that can allow the user to control the operation of the device. For example, a user can operate the control buttons 208a to view one or more 10 measurements of various analytes, such as glucose. In addition, the user can operate the control buttons 208a to view other forms of information, such as graphs, histograms, measurement data, trend measurement data, parameter combination views, wellness indications, and the like. Many 15 parameters, trends, alarms and parameter displays could be output to the display 210a, such as those that are commercially available through a wide variety of noninvasive monitoring devices from Masimo® Corporation of Irvine, Calif.

Furthermore, the controls **208***a* and/or display **210***a* can 20 provide functionality for the user to manipulate settings of the monitoring device **200***a*, such as alarm settings, emitter settings, detector settings, and the like. The monitoring device **200***a* can employ any of a variety of user interface designs, such as frames, menus, touch-screens, and any type 25 of button.

FIG. 2B illustrates another example of a monitoring device 200B. In the depicted embodiment, the monitoring device 200B includes a finger clip sensor 201b connected to a monitor 209b via a cable 212. In the embodiment shown, 30 the monitor 209b includes a display 210b, control buttons 208b and a power button. Moreover, the monitor 209b can advantageously include electronic processing, signal processing, and data storage devices capable of receiving signal data from said sensor 201b, processing the signal data to 35 determine one or more output measurement values indicative of one or more physiological parameters of a monitored patient, and displaying the measurement values, trends of the measurement values, combinations of measurement values, and the like.

The cable 212 connecting the sensor 201b and the monitor 209b can be implemented using one or more wires, optical fiber, flex circuits, or the like. In some embodiments, the cable 212 can employ twisted pairs of conductors in order to minimize or reduce cross-talk of data transmitted from the 45 sensor 201b to the monitor 209b. Various lengths of the cable 212 can be employed to allow for separation between the sensor 201b and the monitor 209b. The cable 212 can be fitted with a connector (male or female) on either end of the cable 212 so that the sensor 201b and the monitor 209b can 50 be connected and disconnected from each other. Alternatively, the sensor 201b and the monitor 209b can be coupled together via a wireless communication link, such as an infrared link, radio frequency channel, or any other wireless communication protocol and channel.

The monitor **209***b* can be attached to the patient. For example, the monitor **209***b* can include a belt clip or straps (see, e.g., FIG. **2**C) that facilitate attachment to a patient's belt, arm, leg, or the like. The monitor **209***b* can also include a fitting, slot, magnet, LEMO snap-click connector, or other connecting mechanism to allow the cable **212** and sensor **201***b* to be attached to the monitor **209**B.

The monitor **209***b* can also include other components, such as a speaker, power button, removable storage or memory (e.g., a flash card slot), an AC power port, and one 65 or more network interfaces, such as a universal serial bus interface or an Ethernet port. For example, the monitor **209***b* 

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can include a display 210b that can indicate a measurement for glucose, for example, in mg/dL. Other analytes and forms of display can also appear on the monitor 209b.

In addition, although a single sensor 201b with a single monitor 209b is shown, different combinations of sensors and device pairings can be implemented. For example, multiple sensors can be provided for a plurality of differing patient types or measurement sites or even patient fingers.

FIG. 2C illustrates yet another example of monitoring device 200C that can house the data collection system 100. Like the monitoring device 200B, the monitoring device 200C includes a finger clip sensor 201c connected to a monitor 209c via a cable 212. The cable 212 can have all of the features described above with respect to FIG. 2B. The monitor 209c can include all of the features of the monitor 200B described above. For example, the monitor 209c includes buttons 208c and a display 210c. The monitor 209c shown also includes straps 214c that allow the monitor 209c to be attached to a patient's limb or the like.

FIG. 2D illustrates vet another example of monitoring device 200D that can house the data collection system 100. Like the monitoring devices 200B and 200C, the monitoring device 200D includes a finger clip sensor 201d connected to a monitor 209d via a cable 212. The cable 212 can have all of the features described above with respect to FIG. 2B. In addition to having some or all of the features described above with respect to FIGS. 2B and 2C, the monitoring device 200D includes an optional universal serial bus (USB) port 216 and an Ethernet port 218. The USB port 216 and the Ethernet port 218 can be used, for example, to transfer information between the monitor 209d and a computer (not shown) via a cable. Software stored on the computer can provide functionality for a user to, for example, view physiological data and trends, adjust settings and download firmware updates to the monitor 209b, and perform a variety of other functions. The USB port 216 and the Ethernet port 218 can be included with the other monitoring devices 200A, 200B, and 200C described above.

FIGS. 3A through 3C illustrate more detailed examples of embodiments of a sensor 301a. The sensor 301a shown can include all of the features of the sensors 100 and 200 described above.

Referring to FIG. 3A, the sensor 301a in the depicted embodiment is a clothespin-shaped clip sensor that includes an enclosure 302a for receiving a patient's finger. The enclosure 302a is formed by an upper section or emitter shell 304a, which is pivotably connected with a lower section or detector shell 306a. The emitter shell 304a can be biased with the detector shell 306a to close together around a pivot point 303a and thereby sandwich finger tissue between the emitter and detector shells 304a, 306a.

In an embodiment, the pivot point 303a advantageously includes a pivot capable of adjusting the relationship between the emitter and detector shells 304a, 306a to effectively level the sections when applied to a tissue site. In another embodiment, the sensor 301a includes some or all features of the finger clip described in U.S. Publication No. 2006/0211924, incorporated above, such as a spring that causes finger clip forces to be distributed along the finger. Paragraphs [0096] through [0105], which describe this feature, are hereby specifically incorporated by reference.

The emitter shell **304***a* can position and house various emitter components of the sensor **301***a*. It can be constructed of reflective material (e.g., white silicone or plastic) and/or can be metallic or include metallicized plastic (e.g., including carbon and aluminum) to possibly serve as a heat sink. The emitter shell **304***a* can also include absorbing opaque mate-

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rial, such as, for example, black or grey colored material, at various areas, such as on one or more flaps 307a, to reduce ambient light entering the sensor 301a.

The detector shell **306***a* can position and house one or more detector portions of the sensor **301***a*. The detector shell **306***a* can be constructed of reflective material, such as white silicone or plastic. As noted, such materials can increase the usable signal at a detector by forcing light back into the tissue and measurement site (see FIG. 1). The detector shell **306***a* can also include absorbing opaque material at various areas, such as lower area **308***a*, to reduce ambient light entering the sensor **301***a*.

Referring to FIGS. 3B and 3C, an example of finger bed 310 is shown in the sensor 301b. The finger bed 310 includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger bed 310 includes one or more ridges or channels 314. Each of the ridges 314 has a generally convex shape that can facilitate increasing traction or gripping of the patient's finger to the finger bed. Advantageously, the ridges 314 can improve the accuracy of spectroscopic analysis in certain embodiments by reducing noise that can result from a measurement site moving or shaking loose inside of the sensor 301a. The ridges 314 can be made from reflective or opaque materials in some 25 embodiments to further increase SNR. In other implementations, other surface shapes can be used, such as, for example, generally flat, concave, or convex finger beds 310.

Finger bed 310 can also include an embodiment of a tissue thickness adjuster or protrusion 305. The protrusion 305 includes a measurement site contact area 370 (see FIG. 3C) that can contact body tissue of a measurement site. The protrusion 305 can be removed from or integrated with the finger bed 310. Interchangeable, different shaped protrusions 305 can also be provided, which can correspond to 35 different finger shapes, characteristics, opacity, sizes, or the like

Referring specifically to FIG. 3C, the contact area 370 of the protrusion 305 can include openings or windows 320, 321, 322, and 323. When light from a measurement site 40 passes through the windows 320, 321, 322, and 323, the light can reach one or more photodetectors (see FIG. 3E). In an embodiment, the windows 320, 321, 322, and 323 mirror specific detector placements layouts such that light can impinge through the protrusion 305 onto the photodetectors. 45 Any number of windows 320, 321, 322, and 323 can be employed in the protrusion 305 to allow light to pass from the measurement site to the photodetectors.

The windows 320, 321, 322, and 323 can also include shielding, such as an embedded grid of wiring or a conduc- 50 tive glass coating, to reduce noise from ambient light or other electromagnetic noise. The windows 320, 321, 322, and 323 can be made from materials, such as plastic or glass. In some embodiments, the windows 320, 321, 322, and 323 can be constructed from conductive glass, such as indium tin 55 oxide (ITO) coated glass. Conductive glass can be useful because its shielding is transparent, and thus allows for a larger aperture versus a window with an embedded grid of wiring. In addition, in certain embodiments, the conductive glass does not need openings in its shielding (since it is transparent), which enhances its shielding performance. For example, some embodiments that employ the conductive glass can attain up to an about 40% to about 50% greater signal than non-conductive glass with a shielding grid. In addition, in some embodiments, conductive glass can be 65 useful for shielding noise from a greater variety of directions than non-conductive glass with a shielding grid.

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Turning to FIG. 3B, the sensor 301a can also include a shielding 315a, such as a metal cage, box, metal sheet, perforated metal sheet, a metal layer on a non-metal material, or the like. The shielding 315a is provided in the depicted embodiment below or embedded within the protrusion 305 to reduce noise. The shielding 315a can be constructed from a conductive material, such as copper. The shielding 315a can include one or more openings or windows (not shown). The windows can be made from glass or plastic to thereby allow light that has passed through the windows 320, 321, 322, and 323 on an external surface of the protrusion 305 (see FIG. 3C) to pass through to one or more photodetectors that can be enclosed or provided below (see FIG. 3E).

In some embodiments, the shielding cage for shielding 315a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding cage can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108.

In an embodiment, the photodetectors can be positioned within or directly beneath the protrusion 305 (see FIG. 3E). In such cases, the mean optical path length from the emitters to the detectors can be reduced and the accuracy of blood analyte measurement can increase. For example, in one embodiment, a convex bump of about 1 mm to about 3 mm in height and about 10 mm<sup>2</sup> to about 60 mm<sup>2</sup> was found to help signal strength by about an order of magnitude versus other shapes. Of course other dimensions and sizes can be employed in other embodiments. Depending on the properties desired, the length, width, and height of the protrusion 305 can be selected. In making such determinations, consideration can be made of protrusion's 305 effect on blood flow at the measurement site and mean path length for optical radiation passing through openings 320, 321, 322, and 323. Patient comfort can also be considered in determining the size and shape of the protrusion.

In an embodiment, the protrusion 305 can include a pliant material, including soft plastic or rubber, which can somewhat conform to the shape of a measurement site. Pliant materials can improve patient comfort and tactility by conforming the measurement site contact area 370 to the measurement site. Additionally, pliant materials can minimize or reduce noise, such as ambient light. Alternatively, the protrusion 305 can be made from a rigid material, such as hard plastic or metal.

Rigid materials can improve measurement accuracy of a blood analyte by conforming the measurement site to the contact area 370. The contact area 370 can be an ideal shape for improving accuracy or reducing noise. Selecting a material for the protrusion 305 can include consideration of materials that do not significantly alter blood flow at the measurement site. The protrusion 305 and the contact area 370 can include a combination of materials with various characteristics.

The contact area 370 serves as a contact surface for the measurement site. For example, in some embodiments, the contact area 370 can be shaped for contact with a patient's finger. Accordingly, the contact area 370 can be sized and shaped for different sizes of fingers. The contact area 370 can be constructed of different materials for reflective purposes as well as for the comfort of the patient. For example,

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the contact area 370 can be constructed from materials having various hardness and textures, such as plastic, gel, foam, and the like.

The formulas and analysis that follow with respect to FIG. 5 provide insight into how selecting these variables can alter 5 transmittance and intensity gain of optical radiation that has been applied to the measurement site. These examples do not limit the scope of this disclosure.

Referring to FIG. **5**, a plot **500** is shown that illustrates examples of effects of embodiments of the protrusion **305** on 10 the SNR at various wavelengths of light. As described above, the protrusion **305** can assist in conforming the tissue and effectively reduce its mean path length. In some instances, this effect by the protrusion **305** can have significant impact on increasing the SNR.

According to the Beer Lambert law, a transmittance of light (I) can be expressed as follows:  $1=l_o *e^{-m^*b^*c}$ , where  $l_o$  is the initial power of light being transmitted, m is the path length traveled by the light, and the component "b\*c" corresponds to the bulk absorption of the light at a specific 20 wavelength of light. For light at about 1600 nm to about 1700 nm, for example, the bulk absorption component is generally around 0.7 mm<sup>-1</sup>. Assuming a typical finger thickness of about 12 mm and a mean path length of 20 mm due to tissue scattering, then  $1=l_o *e^{(-20^*0.7)}$ .

In an embodiment where the protrusion 305 is a convex bump, the thickness of the finger can be reduced to 10 mm (from 12 mm) for some fingers and the effective light mean path is reduced to about 16.6 mm from 20 mm (see box 510). This results in a new transmittance,  $l_1 = l_0 * e^{(-16.6*0.7)}$ . A 30 curve for a typical finger (having a mean path length of 20 mm) across various wavelengths is shown in the plot 500 of FIG. 5. The plot 500 illustrates potential effects of the protrusion 305 on the transmittance. As illustrated, comparing 1 and  $l_1$  results in an intensity gain of  $e^{(-16.6*0.7)}/e^{(-35)}$ 20\*0.7), which is about a 10 times increase for light in the about 1600 nm to about 1700 nm range. Such an increase can affect the SNR at which the sensor can operate. The foregoing gains can be due at least in part to the about 1600 nm to about 1700 nm range having high values in bulk 40 absorptions (water, protein, and the like), e.g., about 0.7 mm<sup>-1</sup>. The plot **500** also shows improvements in the visible/ near-infrared range (about 600 nm to about 1300 nm).

Turning again to FIGS. 3A through 3C, an example heat sink 350a is also shown. The heat sink 350a can be attached 45 to, or protrude from an outer surface of, the sensor 301a, thereby providing increased ability for various sensor components to dissipate excess heat. By being on the outer surface of the sensor 301a in certain embodiments, the heat sink 350a can be exposed to the air and thereby facilitate 50 more efficient cooling. In an embodiment, one or more of the emitters (see FIG. 1) generate sufficient heat that inclusion of the heat sink 350a can advantageously allows the sensor 301a to remain safely cooled. The heat sink 350a can include one or more materials that help dissipate heat, such 55 as, for example, aluminum, steel, copper, carbon, combinations of the same, or the like. For example, in some embodiments, the emitter shell 304a can include a heat conducting material that is also readily and relatively inexpensively moldable into desired shapes and forms.

In some embodiments, the heat sink **350***a* includes metalicized plastic. The metalicized plastic can include aluminum and carbon, for example. The material can allow for improved thermal conductivity and diffusivity, which can increase commercial viability of the heat sink. In some 65 embodiments, the material selected to construct the heat sink **350***a* can include a thermally conductive liquid crystalline

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polymer, such as CoolPoly® D5506, commercially available from Cool Polymers®, Inc. of Warwick, R.I. Such a material can be selected for its electrically non-conductive and dielectric properties so as, for example, to aid in electrical shielding. In an embodiment, the heat sink **350***a* provides improved heat transfer properties when the sensor **301***a* is active for short intervals of less than a full day's use. In an embodiment, the heat sink **350***a* can advantageously provide improved heat transfers in about three (3) to about four (4) minute intervals, for example, although a heat sink **350***a* can be selected that performs effectively in shorter or longer intervals.

Moreover, the heat sink 350a can have different shapes and configurations for aesthetic as well as for functional purposes. In an embodiment, the heat sink is configured to maximize heat dissipation, for example, by maximizing surface area. In an embodiment, the heat sink 350a is molded into a generally curved surface and includes one or more fins, undulations, grooves, or channels. The example heat sink 350a shown includes fins 351a (see FIG. 3A).

An alternative shape of a sensor 301b and heat sink 350b is shown in FIG. 3D. The sensor 301b can include some or all of the features of the sensor 301a. For example, the sensor 301b includes an enclosure 302b formed by an 25 emitter shell 304b and a detector shell 306b, pivotably connected about a pivot 303a. The emitter shell 304b can also include absorbing opaque material on one or more flaps 307b, and the detector shell 306a can also include absorbing opaque material at various areas, such as lower area 308b.

However, the shape of the sensor 301b is different in this embodiment. In particular, the heat sink 350b includes comb protrusions 351b. The comb protrusions 351b are exposed to the air in a similar manner to the fins 351a of the heat sink 350a, thereby facilitating efficient cooling of the sensor 301b.

FIG. 3E illustrates a more detailed example of a detector shell 306b of the sensor 301b. The features described with respect to the detector shell 306b can also be used with the detector shell 306a of the sensor 301a.

As shown, the detector shell 306b includes detectors 316. The detectors 316 can have a predetermined spacing 340 from each other, or a spatial relationship among one another that results in a spatial configuration. This spatial configuration can purposefully create a variation of path lengths among detectors 316 and the emitter discussed above.

In the depicted embodiment, the detector shell 316 can hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays can also be useful to detect light piping (e.g., light that bypasses measurement site 102). In the detector shell 316, walls can be provided to separate the individual photodiode arrays to prevent or reduce mixing of light signals from distinct quadrants. In addition, the detector shell 316 can be covered by windows of transparent material, such as glass, plastic, or the like, to allow maximum or increased transmission of power light captured. In various embodiments, the transparent materials used can also be partially transparent or translucent or can otherwise pass some or all of the optical radiation passing through 60 them. As noted, this window can include some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

As further illustrated by FIG. 3E, the detectors 316 can have a spatial configuration of a grid. However, the detectors 316 can be arranged in other configurations that vary the path length. For example, the detectors 316 can be arranged in a linear array, a logarithmic array, a two-dimensional

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array, a zig-zag pattern, or the like. Furthermore, any number of the detectors 316 can be employed in certain embodi-

FIG. 3F illustrates another embodiment of a sensor 301f. The sensor 301f can include some or all of the features of the 5 sensor 301a of FIG. 3A described above. For example, the sensor 301f includes an enclosure 302f formed by an upper section or emitter shell 304f, which is pivotably connected with a lower section or detector shell 306f around a pivot point 303f. The emitter shell 304f can also include absorbing opaque material on various areas, such as on one or more flaps 307f, to reduce ambient light entering the sensor 301f. The detector shell 306f can also include absorbing opaque material at various areas, such as a lower area 308f. The sensor 301f also includes a heat sink 350f, which includes 15 fins 351f.

In addition to these features, the sensor 301f includes a flex circuit cover 360, which can be made of plastic or another suitable material. The flex circuit cover 360 can cover and thereby protect a flex circuit (not shown) that 20 extends from the emitter shell 304f to the detector shell 306f. An example of such a flex circuit is illustrated in U.S. Publication No. 2006/0211924, incorporated above (see FIG. 46 and associated description, which is hereby specifically incorporated by reference). The flex circuit cover 360 25 is shown in more detail below in FIG. 17.

In addition, sensors 301a-f has extra length—extends to second joint on finger-Easier to place, harder to move due to cable, better for light piping.

FIGS. 4A through 4C illustrate example arrangements of 30 a protrusion 405, which is an embodiment of the protrusion 305 described above. In an embodiment, the protrusion 405 can include a measurement site contact area 470. The measurement site contact area 470 can include a surface that into a flat or relatively flat surface.

The protrusion 405 can have dimensions that are suitable for a measurement site such as a patient's finger. As shown, the protrusion 405 can have a length 400, a width 410, and a height 430. The length 400 can be from about 9 to about 40 11 millimeters, e.g., about 10 millimeters. The width 410 can be from about 7 to about 9 millimeters, e.g., about 8 millimeters. The height 430 can be from about 0.5 millimeters to about 3 millimeters, e.g., about 2 millimeters. In an embodiment, the dimensions 400, 410, and 430 can be 45 selected such that the measurement site contact area 470 includes an area of about 80 square millimeters, although larger and smaller areas can be used for different sized tissue for an adult, an adolescent, or infant, or for other considerations.

The measurement site contact area 470 can also include differently shaped surfaces that conform the measurement site into different shapes. For example, the measurement site contact area 470 can be generally curved and/or convex with respect to the measurement site. The measurement site 55 contact area 470 can be other shapes that reduce or even minimize air between the protrusion 405 and/or the measurement site. Additionally, the surface pattern of the measurement site contact area 470 can vary from smooth to bumpy, e.g., to provide varying levels of grip.

In FIGS. 4A and 4C, openings or windows 420, 421, 422, and 423 can include a wide variety of shapes and sizes, including for example, generally square, circular, triangular, or combinations thereof. The windows 420, 421, 422, and 423 can be of non-uniform shapes and sizes. As shown, the 65 windows 420, 421, 422, and 423 can be evenly spaced out in a grid like arrangement. Other arrangements or patterns of

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arranging the windows 420, 421, 422, and 423 are possible. For example, the windows **420**, **421**, **422**, and **423** can be placed in a triangular, circular, or linear arrangement. In some embodiments, the windows 420, 421, 422, and 423 can be placed at different heights with respect to the finger bed 310 of FIG. 3. The windows 420, 421, 422, and 423 can also mimic or approximately mimic a configuration of, or even house, a plurality of detectors.

FIGS. 6A through 6D illustrate another embodiment of a protrusion 605 that can be used as the tissue shaper 105 described above or in place of the protrusions 305, 405 described above. The depicted protrusion 605 is a partially cylindrical lens having a partial cylinder 608 and an extension 610. The partial cylinder 608 can be a half cylinder in some embodiments; however, a smaller or greater portion than half of a cylinder can be used. Advantageously, in certain embodiments, the partially cylindrical protrusion 605 focuses light onto a smaller area, such that fewer detectors can be used to detect the light attenuated by a measurement

FIG. 6A illustrates a perspective view of the partially cylindrical protrusion 605. FIG. 6B illustrates a front elevation view of the partially cylindrical protrusion 605. FIG. 6C illustrates a side view of the partially cylindrical protrusion 605. FIG. 6D illustrates a top view of the partially cylindrical protrusion 605.

Advantageously, in certain embodiments, placing the partially cylindrical protrusion 605 over the photodiodes in any of the sensors described above adds multiple benefits to any of the sensors described above. In one embodiment, the partially cylindrical protrusion 605 penetrates into the tissue and reduces the path length of the light traveling in the tissue, similar to the protrusions described above.

The partially cylindrical protrusion 605 can also collect molds body tissue of a measurement site, such as a finger, 35 light from a large surface and focus down the light to a smaller area. As a result, in certain embodiments, signal strength per area of the photodiode can be increased. The partially cylindrical protrusion 605 can therefore facilitate a lower cost sensor because, in certain embodiments, less photodiode area can be used to obtain the same signal strength. Less photodiode area can be realized by using smaller photodiodes or fewer photodiodes (see, e.g., FIG. 14). If fewer or smaller photodiodes are used, the partially cylindrical protrusion 605 can also facilitate an improved SNR of the sensor because fewer or smaller photodiodes can have less dark current.

> The dimensions of the partially cylindrical protrusion 605 can vary based on, for instance, a number of photodiodes used with the sensor. Referring to FIG. 6C, the overall height of the partially cylindrical protrusion 605 (measurement "a") in some implementations is about 1 to about 3 mm. A height in this range can allow the partially cylindrical protrusion 605 to penetrate into the pad of the finger or other tissue and reduce the distance that light travels through the tissue. Other heights, however, of the partially cylindrical protrusion 605 can also accomplish this objective. For example, the chosen height of the partially cylindrical protrusion 605 can be selected based on the size of the measurement site, whether the patient is an adult or child, and so on. In an embodiment, the height of the protrusion 605 is chosen to provide as much tissue thickness reduction as possible while reducing or preventing occlusion of blood vessels in the

> Referring to FIG. 6D, the width of the partially cylindrical protrusion 605 (measurement "b") can be about 3 to about 5 mm. In one embodiment, the width is about 4 mm. In one embodiment, a width in this range provides good penetration

of the partially cylindrical protrusion **605** into the tissue to reduce the path length of the light. Other widths, however, of the partially cylindrical protrusion **605** can also accomplish this objective. For example, the width of the partially cylindrical protrusion **605** can vary based on the size of the measurement site, whether the patient is an adult or child, and so on. In addition, the length of the protrusion **605** could be about 10 mm, or about 8 mm to about 12 mm, or smaller than 8 mm or greater than 12 mm.

In certain embodiments, the focal length (f) for the partially cylindrical protrusion 605 can be expressed as:

$$f = \frac{R}{n-1}$$

where R is the radius of curvature of the partial cylinder **608** and n is the index of refraction of the material used. In certain embodiments, the radius of curvature can be between about 1.5 mm and about 2 mm. In another embodiment, the partially cylindrical protrusion **605** can include a material, such as nBK7 glass, with an index of refraction of around 1.5 at 1300 nm, which can provide focal lengths of between about 3 mm and about 4 mm.

A partially cylindrical protrusion 605 having a material with a higher index of refraction such as nSF11 glass (e.g., n=1.75 at 1300 nm) can provide a shorter focal length and possibly a smaller photodiode chip, but can also cause higher reflections due to the index of refraction mismatch with air. Many types of glass or plastic can be used with index of refraction values ranging from, for example, about 1.4 to about 1.9. The index of refraction of the material of the protrusion 605 can be chosen to improve or optimize the light focusing properties of the protrusion 605. A plastic partially cylindrical protrusion 605 could provide the cheapest option in high volumes but can also have some undesired light absorption peaks at wavelengths higher than 1500 nm. Other focal lengths and materials having different indices of refraction can be used for the partially cylindrical protrusion 40 605.

Placing a photodiode at a given distance below the partially cylindrical protrusion 605 can facilitate capturing some or all of the light traveling perpendicular to the lens within the active area of the photodiode (see FIG. 14). 45 Different sizes of the partially cylindrical protrusion 605 can use different sizes of photodiodes. The extension 610 added onto the bottom of the partial cylinder 608 is used in certain embodiments to increase the height of the partially cylindrical protrusion 605. In an embodiment, the added height is 50 such that the photodiodes are at or are approximately at the focal length of the partially cylindrical protrusion 605. In an embodiment, the added height provides for greater thinning of the measurement site. In an embodiment, the added height assists in deflecting light piped through the sensor. This is 55 because light piped around the sensor passes through the side walls of the added height without being directed toward the detectors. The extension 610 can also further facilitate the protrusion 605 increasing or maximizing the amount of light that is provided to the detectors. In some embodiments, 60 the extension 610 can be omitted.

FIG. 6E illustrates another view of the sensor 301f of FIG. 3F, which includes an embodiment of a partially cylindrical protrusion 605b. Like the sensor 301A shown in FIGS. 3B and 3C, the sensor 301f includes a finger bed 310f. The 65 finger bed 310f includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger

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bed 310f also includes the ridges or channels 314 described above with respect to FIGS. 3B and 3C.

The example of finger bed 310f shown also includes the protrusion 605b, which includes the features of the protrusion 605 described above. In addition, the protrusion 605b also includes chamfered edges 607 on each end to provide a more comfortable surface for a finger to slide across (see also FIG. 14D). In another embodiment, the protrusion 605b could instead include a single chamfered edge 607 proximal to the ridges 314. In another embodiment, one or both of the chamfered edges 607 could be rounded.

The protrusion **605***b* also includes a measurement site contact area **670** that can contact body tissue of a measurement site. The protrusion **605***b* can be removed from or integrated with the finger bed **310***f*. Interchangeable, differently shaped protrusions **605***b* can also be provided, which can correspond to different finger shapes, characteristics, opacity, sizes, or the like.

FIGS. 7A and 7B illustrate block diagrams of sensors 701
that include example arrangements of conductive glass or
conductive coated glass for shielding. Advantageously, in
certain embodiments, the shielding can provide increased
SNR. The features of the sensors 701 can be implemented
with any of the sensors 101, 201, 301 described above.

25 Although not shown, the partially cylindrical protrusion 605
of FIG. 6 can also be used with the sensors 701 in certain
embodiments.

For example, referring specifically to FIG. 7A, the sensor 701a includes an emitter housing 704a and a detector housing 706. The emitter housing 704a includes LEDs 104. The detector housing 706a includes a tissue bed 710a with an opening or window 703a, the conductive glass 730a, and one or more photodiodes for detectors 106 provided on a submount 707a.

During operation, a finger 102 can be placed on the tissue bed 710a and optical radiation can be emitted from the LEDs 104. Light can then be attenuated as it passes through or is reflected from the tissue of the finger 102. The attenuated light can then pass through the opening 703a in the tissue bed 710a. Based on the received light, the detectors 106 can provide a detector signal 107, for example, to the front end interface 108 (see FIG. 1).

In the depicted embodiment, the conductive glass 730 is provided in the opening 703. The conductive glass 730 can thus not only permit light from the finger to pass to the detectors 106, but it can also supplement the shielding of the detectors 106 from noise. The conductive glass 730 can include a stack or set of layers. In FIG. 7A, the conductive glass 730a is shown having a glass layer 731 proximate the finger 102 and a conductive layer 733 electrically coupled to the shielding 790a.

In an embodiment, the conductive glass 730a can be coated with a conductive, transparent or partially transparent material, such as a thin film of indium tin oxide (ITO). To supplement electrical shielding effects of a shielding enclosure 790a, the conductive glass 730a can be electrically coupled to the shielding enclosure 790a. The conductive glass 730a can be electrically coupled to the shielding 704a based on direct contact or via other connection devices, such as a wire or another component.

The shielding enclosure **790***a* can be provided to encompass the detectors **106** to reduce or prevent noise. For example, the shielding enclosure **790***a* can be constructed from a conductive material, such as copper, in the form of a metal cage. The shielding or enclosure a can include an opaque material to not only reduce electrical noise, but also ambient optical noise.

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In some embodiments, the shielding enclosure 790a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. 5 Furthermore, the shielding enclosure 790a can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108

Referring to FIG. 7B, another block diagram of an 10 example sensor 701b is shown. A tissue bed 710b of the sensor 701b includes a protrusion 705b, which is in the form of a convex bump. The protrusion 705b can include all of the features of the protrusions or tissue shaping materials described above. For example, the protrusion 705b includes 15 a contact area 370 that comes in contact with the finger 102 and which can include one or more openings 703b. One or more components of conductive glass 730b can be provided in the openings 703. For example, in an embodiment, each of the openings 703 can include a separate window of the 20 conductive glass 730b. In an embodiment, a single piece of the conductive glass 730b can used for some or all of the openings 703b. The conductive glass 730b is smaller than the conductive glass 730a in this particular embodiment.

A shielding enclosure 790b is also provided, which can 25 have all the features of the shielding enclosure 790a. The shielding enclosure 790b is smaller than the shielding enclosure 790a; however, a variety of sizes can be selected for the shielding enclosures 790.

In some embodiments, the shielding enclosure **790***b* can 30 be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding enclosure **790***b* can also be used 35 to house various other components, such as sigma delta components for various embodiments of front end interfaces **108** 

FIGS. 8A through 8D illustrate a perspective view, side views, and a bottom elevation view of the conductive glass 40 described above with respect to the sensors 701a, 701b. As shown in the perspective view of FIG. 8A and side view of FIG. 8B, the conductive glass 730 includes the electrically conductive material 733 described above as a coating on the glass layer 731 described above to form a stack. In an 45 embodiment where the electrically conductive material 733 includes indium tin oxide, surface resistivity of the electrically conductive material 733 can range approximately from 30 ohms per square inch to 500 ohms per square inch, or approximately 30, 200, or 500 ohms per square inch. As 50 would be understood by a person of skill in the art from the present disclosure, other resistivities can also be used which are less than 30 ohms or more than 500 ohms. Other transparent, electrically conductive materials can be used as the material 733.

Although the conductive material **733** is shown spread over the surface of the glass layer **731**, the conductive material **733** can be patterned or provided on selected portions of the glass layer **731**. Furthermore, the conductive material **733** can have uniform or varying thickness depending on a desired transmission of light, a desired shielding effect, and other considerations.

In FIG. 8C, a side view of a conductive glass 830a is shown to illustrate an embodiment where the electrically conductive material 733 is provided as an internal layer 65 between two glass layers 731, 835. Various combinations of integrating electrically conductive material 733 with glass

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are possible. For example, the electrically conductive material 733 can be a layer within a stack of layers. This stack of layers can include one or more layers of glass 731, 835, as well as one or more layers of conductive material 733. The stack can include other layers of materials to achieve desired characteristics.

In FIG. 8D, a bottom perspective view is shown to illustrate an embodiment where a conductive glass 830b can include conductive material 837 that occupies or covers a portion of a glass layer 839. This embodiment can be useful, for example, to create individual, shielded windows for detectors 106, such as those shown in FIG. 3C. The conductive material 837 can be patterned to include an area 838 to allow light to pass to detectors 106 and one or more strips 841 to couple to the shielding 704 of FIG. 7.

Other configurations and patterns for the conductive material can be used in certain embodiments, such as, for example, a conductive coating lining periphery edges, a conductive coating outlaid in a pattern including a grid or other pattern, a speckled conductive coating, coating outlaid in lines in either direction or diagonally, varied thicknesses from the center out or from the periphery in, or other suitable patterns or coatings that balance the shielding properties with transparency considerations.

FIG. 9 depicts an example graph 900 that illustrates comparative results obtained by an example sensor having components similar to those disclosed above with respect to FIGS. 7 and 8. The graph 900 depicts the results of the percentage of transmission of varying wavelengths of light for different types of windows used in the sensors described above.

A line 915 on the graph 900 illustrates example light transmission of a window made from plain glass. As shown, the light transmission percentage of varying wavelengths of light is approximately 90% for a window made from plain glass. A line 920 on the graph 900 demonstrates an example light transmission percentage for an embodiment in which a window is made from glass having an ITO coating with a surface resistivity of 500 ohms per square inch. A line 925 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 200 ohms per square inch. A line 930 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 30 ohms per square inch.

The light transmission percentage for a window with currently available embedded wiring can have a light trans50 mission percentage of approximately 70%. This lower percentage of light transmission can be due to the opacity of the wiring employed in a currently available window with wiring. Accordingly, certain embodiments of glass coatings described herein can employ, for example, ITO coatings with different surface resistivity depending on the desired light transmission, wavelengths of light used for measurement, desired shielding effect, and other criteria.

FIGS. 10A through 10B illustrate comparative noise floors of example implementations of the sensors described above. Noise can include optical noise from ambient light and electro-magnetic noise, for example, from surrounding electrical equipment. In FIG. 10A, a graph 1000 depicts possible noise floors for different frequencies of noise for an embodiment in which one of the sensors described above included separate windows for four (4) detectors 106. One or more of the windows included an embedded grid of wiring as a noise shield. Symbols 1030-1033 illustrate the

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noise floor performance for this embodiment. As can be seen, the noise floor performance can vary for each of the openings and based on the frequency of the noise.

In FIG. 10B, a graph 1050 depicts a noise floor for frequencies of noise 1070 for an embodiment in which the sensor included separate openings for four (4) detectors 106 and one or more windows that include an ITO coating. In this embodiment, a surface resistivity of the ITO used was about 500 ohms per square inch. Symbols 1080-1083 illustrate the noise floor performance for this embodiment. As can be seen, the noise floor performance for this embodiment can vary less for each of the openings and provide lower noise floors in comparison to the embodiment of FIG. 10A

FIG. 11A illustrates an example structure for configuring the set of optical sources of the emitters described above. As shown, an emitter 104 can include a driver 1105, a thermistor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, 25 other thermistors can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such a temperature can also be helpful in correcting for wavelength drift due to changes in water absorption, which can be 30 temperature dependent, thereby providing more accurate data useful in detecting blood analytes like glucose. In addition, using a thermistor or other type of temperature sensitive device may be useful for detecting extreme temperatures at the measurement site that are too hot or too cold. 35 The presence of low perfusion may also be detected, for example, when the finger of a patient has become too cold. Moreover, shifts in temperature at the measurement site can alter the absorption spectrum of water and other tissue in the measurement cite. A thermistor's temperature reading can be 40 used to adjust for the variations in absorption spectrum changes in the measurement site.

The driver 1105 can provide pulses of current to the emitter 1104. In an embodiment, the driver 1105 drives the emitter 1104 in a progressive fashion, for example, in an 45 alternating manner based on a control signal from, for example, a processor (e.g., the processor 110). For example, the driver 1105 can drive the emitter 1104 with a series of pulses to about 1 milliwatt (mW) for visible light to light at about 1300 nm and from about 40 mW to about 100 mW for 50 light at about 1600 nm to about 1700 nm. However, a wide number of driving powers and driving methodologies can be used. The driver 1105 can be synchronized with other parts of the sensor and can minimize or reduce any jitter in the timing of pulses of optical radiation emitted from the emitter 55 1104. In some embodiments, the driver 1105 is capable of driving the emitter 1104 to emit an optical radiation in a pattern that varies by less than about 10 parts-per-million; however other amounts of variation can be used.

The submount 1106 provides a support structure in certain 60 embodiments for aligning the top-emitting LEDs 1102 and the side-emitting LEDs 1104 so that their optical radiation is transmitted generally towards the measurement site. In some embodiments, the submount 1106 is also constructed of aluminum nitride (AlN) or beryllium oxide (BEO) for heat 65 dissipation, although other materials or combinations of materials suitable for the submount 1106 can be used.

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FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring a blood constituent or analyte like glucose. In some embodiments, emitter 104 may be driven in a progressive fashion to minimize noise and increase SNR of sensor 101. For example, emitter 104 may be driven based on a progression of power/current delivered to LEDs 1102 and 1104.

In some embodiments, emitter 104 may be configured to emit pulses centered about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about 1665 nm. In another embodiment, the emitter 104 may emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of course, emitter 104 may be configured to transmit any of a variety of wavelengths of visible, or near-infrared optical radiation.

istor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, other thermistors can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such

For example, as shown in FIG. 11B, the sequence of optical radiation pulses are shown having a logarithmic-like progression in power/current. In some embodiments, the timing of these pulses is based on a cycle of about 400 slots running at 48 kHz (e.g. each time slot may be approximately 0.02 ms or 20 microseconds). An artisan will recognize that term "slots" includes its ordinary meaning, which includes a time period that may also be expressed in terms of a frequency. In the example shown, pulses from top emitting LEDs 1102 may have a pulse width of about 40 time slots (e.g., about 0.8 ms) and an off period of about 4 time slots in between. In addition, pulses from side emitting LEDs 1104 (e.g., or a laser diode) may have a pulse width of about 60 time slots (e.g., about 1.25 ms) and a similar off period of about 4 time slots. A pause of about 70 time slots (e.g. 1.5 ms) may also be provided in order to allow driver circuit 1105 to stabilize after operating at higher current/power.

As shown in FIG. 11B, top emitting LEDs 1102 may be initially driven with a power to approximately 1 mW at a current of about 20-100 mA. Power in these LEDs may also be modulated by using a filter or covering of black dye to reduce power output of LEDs. In this example, top emitting LEDs 1102 may be driven at approximately 0.02 to 0.08 mW. The sequence of the wavelengths may be based on the current requirements of top emitting LEDs 502 for that particular wavelength. Of course, in other embodiments, different wavelengths and sequences of wavelengths may be output from emitter 104.

Subsequently, side emitting LEDs 1104 may be driven at higher powers, such as about 40-100 mW and higher currents of about 600-800 mA. This higher power may be employed in order to compensate for the higher opacity of tissue and water in measurement site 102 to these wavelengths. For example, as shown, pulses at about 1630 nm, about 1660 nm, and about 1615 nm may be output with progressively higher power, such as at about 40 mW, about 50 mW, and about 60 mW, respectively. In this embodiment, the order of wavelengths may be based on the optical characteristics of that wavelength in tissue as well as the

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current needed to drive side emitting LEDs 1104. For example, in this embodiment, the optical pulse at about 1615 nm is driven at the highest power due to its sensitivity in detecting analytes like glucose and the ability of light at this wavelength to penetrate tissue. Of course, different wavelengths and sequences of wavelengths may be output from emitter 104.

As noted, this progression may be useful in some embodiments because it allows the circuitry of driver circuit 1105 to stabilize its power delivery to LEDs 1102 and 1104. 10 Driver circuit 1105 may be allowed to stabilize based on the duty cycle of the pulses or, for example, by configuring a variable waiting period to allow for stabilization of driver circuit 1105. Of course, other variations in power/current and wavelength may also be employed in the present disclosure.

Modulation in the duty cycle of the individual pulses may also be useful because duty cycle can affect the signal noise ratio of the system 100. That is, as the duty cycle is increased so may the signal to noise ratio.

Furthermore, as noted above, driver circuit 1105 may monitor temperatures of the LEDs 1102 and 1104 using the thermistor 1120 and adjust the output of LEDs 1102 and 1104 accordingly. Such a temperature may be to help sensor 101 correct for wavelength drift due to changes in water 25 absorption, which can be temperature dependent.

FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. As shown, the emitter 104 can include components mounted on a substrate 1108 and on submount 30 1106. In particular, top-emitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108. Side emitting LEDS 1104 may be mounted on submount 1106. As noted, side-emitting LEDs 1104 may be included in emitter 104 for emitting near infrared light.

As also shown, the sensor of FIG. 11C may include a thermistor 1120. As noted, the thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to 40 heating. In addition, other thermistors (not shown) can be employed, for example, to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby 45 providing more accurate data useful in detecting blood analytes like glucose.

In some embodiments, the emitter 104 may be implemented without the use of side emitting LEDs. For example, certain blood constituents, such as total hemoglobin, can be 50 measured by embodiments of the disclosure without the use of side emitting LEDs. FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. In particular, an emitter 104 that is configured for a blood constituent, such as total 55 hemoglobin, is shown. The emitter 104 can include components mounted on a substrate 1108. In particular, topemitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108.

As also shown, the emitter of FIG. 11D may include a 60 thermistor 1120. The thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 due to heating.

FIG. 12A illustrates a detector submount 1200 having 65 photodiode detectors that are arranged in a grid pattern on the detector submount 1200 to capture light at different

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quadrants from a measurement site. One detector submount 1200 can be placed under each window of the sensors described above, or multiple windows can be placed over a single detector submount 1200. The detector submount 1200 can also be used with the partially cylindrical protrusion 605 described above with respect to FIG. 6.

The detectors include photodiode detectors 1-4 that are arranged in a grid pattern on the submount **1200** to capture light at different quadrants from the measurement site. As noted, other patterns of photodiodes, such as a linear row, or logarithmic row, can also be employed in certain embodiments

As shown, the detectors 1-4 may have a predetermined spacing from each other, or spatial relationship among one another that result in a spatial configuration. This spatial configuration can be configured to purposefully create a variation of path lengths among detectors 106 and the point light source discussed above.

Detectors may hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays may also be useful to detect light piping (i.e., light that bypasses measurement site 102). As shown, walls may separate the individual photodiode arrays to prevent mixing of light signals from distinct quadrants. In addition, as noted, the detectors may be covered by windows of transparent material, such as glass, plastic, etc., to allow maximum transmission of power light captured. As noted, this window may comprise some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

FIGS. 12B through 12D illustrate a simplified view of exemplary arrangements and spatial configurations of photodiodes for detectors 106. As shown, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a grid pattern on detector submount 1200 to capture light at different quadrants from measurement site 102.

As noted, other patterns of photodiodes may also be employed in embodiments of the present disclosure, including, for example, stacked or other configurations recognizable to an artisan from the disclosure herein. For example, detectors 106 may be arranged in a linear array, a logarithmic array, a two-dimensional array, and the like. Furthermore, an artisan will recognize from the disclosure herein that any number of detectors 106 may be employed by embodiments of the present disclosure.

For example, as shown in FIG. 12B, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a substantially linear configuration on submount 1200. In this embodiment shown, photodiode detectors 1-4 are substantially equally spaced apart (e.g., where the distance D is substantially the same between detectors 1-4).

In FIG. 12C, photodiode detectors 1-4 may be arranged in a substantially linear configuration on submount 1200, but may employ a substantially progressive, substantially logarithmic, or substantially semi-logarithmic spacing (e.g., where distances D1>D2>D3). This arrangement or pattern may be useful for use on a patient's finger and where the thickness of the finger gradually increases.

In FIG. 12D, a different substantially grid pattern on submount 1200 of photodiode detectors 1-4 is shown. As noted, other patterns of detectors may also be employed in embodiments of the present invention.

FIGS. 12E through 12H illustrate several embodiments of photodiodes that may be used in detectors 106. As shown in these figures, a photodiode 1202 of detector 106 may comprise a plurality of active areas 1204. These active areas

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204 may be coupled together via a common cathode 1206 or anode 1208 in order to provide a larger effective detection area.

In particular, as shown in FIG. 12E, photodiode 1202 may comprise two (2) active areas 1204a and 1204b. In FIG. 12F, photodiode 1202 may comprise four (4) active areas 1204c-f. In FIG. 12G, photodiode 1202 may comprise three (3) active areas 1204g-i. In FIG. 12H, photodiode 1202 may comprise nine (9) active areas 1204j-r. The use of smaller active areas may be useful because smaller active areas can be easier to fabricate and can be fabricated with higher purity. However, one skilled in the art will recognize that various sizes of active areas may be employed in the photodiode 1202.

FIG. 13 illustrates an example multi-stream process 1300. The multi-stream process 1300 can be implemented by the data collection system 100 and/or by any of the sensors described above. As shown, a control signal from a signal processor 1310 controls a driver 1305. In response, an emitter 1304 generates a pulse sequence 1303 from its emitter (e.g., its LEDs) into a measurement site or sites 1302. As described above, in some embodiments, the pulse sequence 1303 is controlled to have a variation of about 10 parts per million or less. Of course, depending on the analyte desired, the tolerated variation in the pulse sequence 1303 can be greater (or smaller).

In response to the pulse sequence 1300, detectors 1 to n (n being an integer) in a detector 1306 capture optical radiation from the measurement site 1302 and provide respective streams of output signals. Each signal from one of detectors 1-n can be considered a stream having respective time slots corresponding to the optical pulses from emitter sets 1-n in the emitter 1304. Although n emitters and n detectors are shown, the number of emitters and detectors need not be the same in certain implementations.

A front end interface 1308 can accept these multiple streams from detectors 1-n and deliver one or more signals or composite signal(s) back to the signal processor 1310. A  $_{
m 40}$  stream from the detectors 1-n can thus include measured light intensities corresponding to the light pulses emitted from the emitter 1304.

The signal processor 1310 can then perform various calculations to measure the amount of glucose and other 45 analytes based on these multiple streams of signals. In order to help explain how the signal processor 1310 can measure analytes like glucose, a primer on the spectroscopy employed in these embodiments will now be provided.

Spectroscopy is premised upon the Beer-Lambert law. According to this law, the properties of a material, e.g., glucose present in a measurement site, can be deterministically calculated from the absorption of light traveling through the material. Specifically, there is a logarithmic relation between the transmission of light through a material and the concentration of a substance and also between the transmission and the length of the path traveled by the light. As noted, this relation is known as the Beer-Lambert law.

The Beer-Lambert law is usually written as:

Absorbance A=m\*b\*c, where:

m is the wavelength-dependent molar absorptivity coefficient (usually expressed in units of  $M^{-1}$  cm<sup>-1</sup>);

b is the mean path length; and

c is the analyte concentration (e.g., the desired parameter).

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In spectroscopy, instruments attempt to obtain the analyte concentration (c) by relating absorbance (A) to transmittance (T). Transmittance is a proportional value defined as:

 $T=l/l_o$ , where:

l is the light intensity measured by the instrument from the measurement site; and

l<sub>o</sub> is the initial light intensity from the emitter.

Absorbance (A) can be equated to the transmittance (T) by the equation:

 $A = -\log T$ 

Therefore, substituting equations from above:

 $A = -\log(l/l_o)$ 

In view of this relationship, spectroscopy thus relies on a proportional-based calculation of  $-\log(1/l_o)$  and solving for analyte concentration (c).

Typically, in order to simplify the calculations, spectroscopy will use detectors that are at the same location in order to keep the path length (b) a fixed, known constant. In addition, spectroscopy will employ various mechanisms to definitively know the transmission power (l<sub>o</sub>), such as a photodiode located at the light source. This architecture can be viewed as a single channel or single stream sensor, because the detectors are at a single location.

However, this scheme can encounter several difficulties in measuring analytes, such as glucose. This can be due to the high overlap of absorption of light by water at the wavelengths relevant to glucose as well as other factors, such as high self-noise of the components.

Embodiments of the present disclosure can employ a different approach that in part allows for the measurement of analytes like glucose. Some embodiments can employ a bulk, non-pulsatile measurement in order to confirm or validate a pulsatile measurement. In addition, both the non-pulsatile and pulsatile measurements can employ, among other things, the multi-stream operation described above in order to attain sufficient SNR. In particular, a single light source having multiple emitters can be used to transmit light to multiple detectors having a spatial configuration.

A single light source having multiple emitters can allow for a range of wavelengths of light to be used. For example, visible, infrared, and near infrared wavelengths can be employed. Varying powers of light intensity for different wavelengths can also be employed.

Secondly, the use of multiple-detectors in a spatial configuration allow for a bulk measurement to confirm or validate that the sensor is positioned correctly. This is because the multiple locations of the spatial configuration can provide, for example, topology information that indicates where the sensor has been positioned. Currently available sensors do not provide such information. For example, if the bulk measurement is within a predetermined range of values, then this can indicate that the sensor is positioned correctly in order to perform pulsatile measurements for analytes like glucose. If the bulk measurement is outside of 60 a certain range or is an unexpected value, then this can indicate that the sensor should be adjusted, or that the pulsatile measurements can be processed differently to compensate, such as using a different calibration curve or adjusting a calibration curve. This feature and others allow the embodiments to achieve noise cancellation and noise reduction, which can be several times greater in magnitude that what is achievable by currently available technology.

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In order to help illustrate aspects of the multi-stream measurement approach, the following example derivation is provided. Transmittance (T) can be expressed as:

$$T=e^{-m^*b^*c}$$

In terms of light intensity, this equation can also be rewritten as:

$$l/l_{o} = e^{-m*b*c}$$

Or, at a detector, the measured light (l) can be expressed  $\,$  10 as:

$$l = l_o * e^{-m * b * c}$$

As noted, in the present disclosure, multiple detectors (1 to n) can be employed, which results in  $l_1 \dots l_n$  streams of 15 measurements. Assuming each of these detectors have their own path lengths,  $b_1 \dots b_n$ , from the light source, the measured light intensities can be expressed as:

$$l_{n}=l_{n}*e^{-m*b_{n}*c}$$

The measured light intensities at any two different detectors can be referenced to each other. For example:

$$l_1/l_n \!\!=\!\! (l_o \!\!\!\! *e^{-mb_1c})/(l_o \!\!\!\! *e^{-mb_nc})$$

As can be seen, the terms,  $l_o$ , cancel out and, based on 25 exponent algebra, the equation can be rewritten as:

$$l_1/l_n = e^{-m(b_1-b_n)c}$$

From this equation, the analyte concentration (c) can now be derived from bulk signals  $l_1 \ldots l_n$  and knowing the 30 respective mean path lengths  $b_1$  and  $b_n$ . This scheme also allows for the cancelling out of  $l_o$ , and thus, noise generated by the emitter **1304** can be cancelled out or reduced. In addition, since the scheme employs a mean path length difference, any changes in mean path length and topological 35 variations from patient to patient are easily accounted. Furthermore, this bulk-measurement scheme can be extended across multiple wavelengths. This flexibility and other features allow embodiments of the present disclosure to measure blood analytes like glucose.

For example, as noted, the non-pulsatile, bulk measurements can be combined with pulsatile measurements to more accurately measure analytes like glucose. In particular, the non-pulsatile, bulk measurement can be used to confirm or validate the amount of glucose, protein, etc. in the pulsatile 45 measurements taken at the tissue at the measurement site(s) 1302. The pulsatile measurements can be used to measure the amount of glucose, hemoglobin, or the like that is present in the blood. Accordingly, these different measurements can be combined to thus determine analytes like blood glucose. 50

FIG. 14A illustrates an embodiment of a detector submount 1400a positioned beneath the partially cylindrical protrusion 605 of FIG. 6 (or alternatively, the protrusion 605b). The detector submount 1400a includes two rows 1408a of detectors 1410a. The partially cylindrical protrusion 605 can facilitate reducing the number and/or size of detectors used in a sensor because the protrusion 605 can act as a lens that focuses light onto a smaller area.

To illustrate, in some sensors that do not include the partially cylindrical protrusion 605, sixteen detectors can be 60 used, including four rows of four detectors each. Multiple rows of detectors can be used to measure certain analytes, such as glucose or total hemoglobin, among others. Multiple rows of detectors can also be used to detect light piping (e.g., light that bypasses the measurement site). However, using 65 more detectors in a sensor can add cost, complexity, and noise to the sensor.

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Applying the partially cylindrical protrusion 605 to such a sensor, however, could reduce the number of detectors or rows of detectors used while still receiving the substantially same amount of light, due to the focusing properties of the protrusion 605 (see FIG. 14B). This is the example situation illustrated in FIG. 14—two rows 1408a of detectors 1410a are used instead of four. Advantageously, in certain embodiments, the resulting sensor can be more cost effective, have less complexity, and have an improved SNR, due to fewer and/or smaller photodiodes.

In other embodiments, using the partially cylindrical protrusion 605 can allow the number of detector rows to be reduced to one or three rows of four detectors. The number of detectors in each row can also be reduced. Alternatively, the number of rows might not be reduced but the size of the detectors can be reduced. Many other configurations of detector rows and sizes can also be provided.

FIG. 14B depicts a front elevation view of the partially cylindrical protrusion 605 (or alternatively, the protrusion 605 b) that illustrates how light from emitters (not shown) can be focused by the protrusion 605 onto detectors. The protrusion 605 is placed above a detector submount 1400b having one or more detectors 1410b disposed thereon. The submount 1400b can include any number of rows of detectors 1410, although one row is shown.

Light, represented by rays 1420, is emitted from the emitters onto the protrusion 605. These light rays 1420 can be attenuated by body tissue (not shown). When the light rays 1420 enter the protrusion 605, the protrusion 605 acts as a lens to refract the rays into rays 1422. This refraction is caused in certain embodiments by the partially cylindrical shape of the protrusion 605. The refraction causes the rays 1422 to be focused or substantially focused on the one or more detectors 1410b. Since the light is focused on a smaller area, a sensor including the protrusion 605 can include fewer detectors to capture the same amount of light compared with other sensors.

FIG. 14C illustrates another embodiment of a detector submount 1400c, which can be disposed under the protrusion 605b (or alternatively, the protrusion 605). The detector submount 1400c includes a single row 1408c of detectors 1410c. The detectors are electrically connected to conductors 1412c, which can be gold, silver, copper, or any other suitable conductive material.

The detector submount 1400c is shown positioned under the protrusion 605b in a detector subassembly 1450 illustrated in FIG. 14D. A top-down view of the detector subassembly 1450 is also shown in FIG. 14E. In the detector subassembly 1450, a cylindrical housing 1430 is disposed on the submount 1400c. The cylindrical housing 1430 includes a transparent cover 1432, upon which the protrusion 605b is disposed. Thus, as shown in FIG. 14D, a gap 1434 exists between the detectors 1410c and the protrusion 605b. The height of this gap 1434 can be chosen to increase or maximize the amount of light that impinges on the detectors 1410c.

The cylindrical housing 1430 can be made of metal, plastic, or another suitable material. The transparent cover 1432 can be fabricated from glass or plastic, among other materials. The cylindrical housing 1430 can be attached to the submount 1400c at the same time or substantially the same time as the detectors 1410c to reduce manufacturing costs. A shape other than a cylinder can be selected for the housing 1430 in various embodiments.

In certain embodiments, the cylindrical housing 1430 (and transparent cover 1432) forms an airtight or substantially airtight or hermetic seal with the submount 1400c. As

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a result, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c from fluids and vapors that can cause corrosion. Advantageously, in certain embodiments, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c more effectively than currently-available resin epoxies, which are sometimes applied to solder joints between conductors and detectors.

In embodiments where the cylindrical housing **1430** is at least partially made of metal, the cylindrical housing **1430** can provide noise shielding for the detectors **1410**c. For example, the cylindrical housing **1430** can be soldered to a ground connection or ground plane on the submount **1400**c, which allows the cylindrical housing **1430** to reduce noise. In another embodiment, the transparent cover **1432** can include a conductive material or conductive layer, such as conductive glass or plastic. The transparent cover **1432** can include any of the features of the noise shields **790** described above

The protrusion **605***b* includes the chamfered edges **607** 20 described above with respect to FIG. **6**E. These chamfered edges **607** can allow a patient to more comfortably slide a finger over the protrusion **605***b* when inserting the finger into the sensor **301***f*.

FIG. 14F illustrates a portion of the detector shell 306f, 25 which includes the detectors 1410c on the substrate 1400c. The substrate 1400c is enclosed by a shielding enclosure 1490, which can include the features of the shielding enclosures 790a, 790b described above (see also FIG. 17). The shielding enclosure 1490 can be made of metal. The shielding enclosure 1490 includes a window 1492a above the detectors 1410c, which allows light to be transmitted onto the detectors 1410c.

A noise shield **1403** is disposed above the shielding enclosure **1490**. The noise shield **1403**, in the depicted 35 embodiment, includes a window **1492***a* corresponding to the window **1492***a*. Each of the windows **1492***a*, **1492***b* can include glass, plastic, or can be an opening without glass or plastic. In some embodiments, the windows **1492***a*, **1492***b* may be selected to have different sizes or shapes from each 40 other.

The noise shield 1403 can include any of the features of the conductive glass described above. In the depicted embodiment, the noise shield 1403 extends about three-quarters of the length of the detector shell 306f. In other 45 embodiments, the noise shield 1403 could be smaller or larger. The noise shield 1403 could, for instance, merely cover the detectors 1410c, the submount 1400c, or a portion thereof. The noise shield 1403 also includes a stop 1413 for positioning a measurement site within the sensor 301f. 50 Advantageously, in certain embodiments, the noise shield 1403 can reduce noise caused by light piping.

A thermistor **1470** is also shown. The thermistor **1470** is attached to the submount **1400**c and protrudes above the noise shield **1403**. As described above, the thermistor **1470** 55 can be employed to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby providing more accurate data useful in detecting blood analytes like 60 glucose.

In the depicted embodiment, the detectors 1410c are not enclosed in the cylindrical housing 1430. In an alternative embodiment, the cylindrical housing 1430 encloses the detectors 1410c and is disposed under the noise shield 1403. 65 In another embodiment, the cylindrical housing 1430 encloses the detectors 1410c and the noise shield 1403 is not

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used. If both the cylindrical housing 1403 and the noise shield 1403 are used, either or both can have noise shielding features

FIG. 14G illustrates the detector shell 306f of FIG. 14F, with the finger bed 310f disposed thereon. FIG. 14H illustrates the detector shell 306f of FIG. 14G, with the protrusion 605b disposed in the finger bed 310f.

FIG. 14I illustrates a cutaway view of the sensor 301f. Not all features of the sensor 301f are shown, such as the protrusion 605b. Features shown include the emitter and detector shells 304f, 306f, the flaps 307f, the heat sink 350f and fins 351f, the finger bed 310f, and the noise shield 1403.

In addition to these features, emitters 1404 are depicted in the emitter shell 304f. The emitters 1404 are disposed on a submount 1401, which is connected to a circuit board 1419. The emitters 1404 are also enclosed within a cylindrical housing 1480. The cylindrical housing 1480 can include all of the features of the cylindrical housing 1430 described above. For example, the cylindrical housing 1480 can be made of metal, can be connected to a ground plane of the submount 1401 to provide noise shielding, and can include a transparent cover 1482.

The cylindrical housing 1480 can also protect the emitters 1404 from fluids and vapors that can cause corrosion. Moreover, the cylindrical housing 1480 can provide a gap between the emitters 1404 and the measurement site (not shown), which can allow light from the emitters 1404 to even out or average out before reaching the measurement site.

The heat sink 350f, in addition to including the fins 351f, includes a protuberance 352f that extends down from the fins 351f and contacts the submount 1401. The protuberance 352f can be connected to the submount 1401, for example, with thermal paste or the like. The protuberance 352f can sink heat from the emitters 1404 and dissipate the heat via the fins 351f.

FIGS. 15A and 15B illustrate embodiments of sensor portions 1500A, 15008 that include alternative heat sink features to those described above. These features can be incorporated into any of the sensors described above. For example, any of the sensors above can be modified to use the heat sink features described below instead of or in addition to the heat sink features of the sensors described above.

The sensor portions 1500A, 1500B shown include LED emitters 1504; however, for ease of illustration, the detectors have been omitted. The sensor portions 1500A, 1500B shown can be included, for example, in any of the emitter shells described above.

The LEDs **1504** of the sensor portions **1500**A, **1500**B are connected to a substrate or submount **1502**. The submount **1502** can be used in place of any of the submounts described above. The submount **1502** can be a non-electrically conducting material made of any of a variety of materials, such as ceramic, glass, or the like. A cable **1512** is attached to the submount **1502** and includes electrical wiring **1514**, such as twisted wires and the like, for communicating with the LEDs **1504**. The cable **1512** can correspond to the cables **212** described above.

Although not shown, the cable 1512 can also include electrical connections to a detector. Only a portion of the cable 1512 is shown for clarity. The depicted embodiment of the cable 1512 includes an outer jacket 1510 and a conductive shield 1506 disposed within the outer jacket 1510. The conductive shield 1506 can be a ground shield or the like that is made of a metal such as braided copper or aluminum. The conductive shield 1506 or a portion of the conductive shield 1506 can be electrically connected to the submount

1502 and can reduce noise in the signal generated by the sensor 1500A, 1500B by reducing RF coupling with the wires 1514. In alternative embodiments, the cable 1512 does not have a conductive shield. For example, the cable 1512 could be a twisted pair cable or the like, with one wire of the 5 twisted pair used as a heat sink.

Referring specifically to FIG. 15A, in certain embodiments, the conductive shield 1506 can act as a heat sink for the LEDs 1504 by absorbing thermal energy from the LEDs 1504 and/or the submount 1502. An optional heat insulator 10 1520 in communication with the submount 1502 can also assist with directing heat toward the conductive shield 1506. The heat insulator 1520 can be made of plastic or another suitable material. Advantageously, using the conductive shield 1506 in the cable 1512 as a heat sink can, in certain 15 embodiments, reduce cost for the sensor.

Referring to FIG. 15B, the conductive shield 1506 can be attached to both the submount 1502 and to a heat sink layer 1530 sandwiched between the submount 1502 and the optional insulator 1520. Together, the heat sink layer 1530 20 and the conductive shield 1506 in the cable 1512 can absorb at least part of the thermal energy from the LEDs and/or the submount 1502.

FIGS. 15C and 15D illustrate implementations of a sensor portion 1500C that includes the heat sink features of the 25 sensor portion 1500A described above with respect to FIG. 15A. The sensor portion 1500C includes the features of the sensor portion 1500A, except that the optional insulator 1520 is not shown. FIG. 15D is a side cutaway view of the sensor portion 1500C that shows the emitters 1504.

The cable **1512** includes the outer jacket **1510** and the conductive shield **1506**. The conductive shield **1506** is soldered to the submount **1502**, and the solder joint **1561** is shown. In some embodiments, a larger solder joint **1561** can assist with removing heat more rapidly from the emitters **1504**. Various connections **1563** between the submount **1502** and a circuit board **1519** are shown. In addition, a cylindrical housing **1580**, corresponding to the cylindrical housing **1480** of FIG. **14I**, is shown protruding through the circuit board **1519**. The emitters **1504** are enclosed in the cylindrical to transimpedance photodiodes in noise model to tionally, those the impedance noise. However, the applicants: housing **1580**.

FIGS. 15E and 15F illustrate implementations of a sensor portion 1500E that includes the heat sink features of the sensor portion 1500B described above with respect to FIG. 15B. The sensor portion 1500E includes the heat sink layer 45 1530. The heat sink layer 1530 can be a metal plate, such as a copper plate or the like. The optional insulator 1520 is not shown. FIG. 15F is a side cutaway view of the sensor portion 1500E that shows the emitters 1504.

In the depicted embodiment, the conductive shield **1506** 50 of the cable **1512** is soldered to the heat sink layer **1530** instead of the submount **1502**. The solder joint **1565** is shown. In some embodiments, a larger solder joint **1565** can assist with removing heat more rapidly from the emitters **1504**. Various connections **1563** between the submount **1502** 55 and a circuit board **1519** are shown. In addition, the cylindrical housing **1580** is shown protruding through the circuit board **1519**. The emitters **1504** are enclosed in the cylindrical housing **1580**.

FIGS. 15G and 15H illustrate embodiments of connector 60 features that can be used with any of the sensors described above with respect to FIGS. 1 through 15F. Referring to FIG. 15G, the circuit board 1519 includes a female connector 1575 that mates with a male connector 1577 connected to a daughter board 1587. The daughter board 1587 includes 65 connections to the electrical wiring 1514 of the cable 1512. The connected boards 1519, 1587 are shown in FIG. 15H.

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Also shown is a hole 1573 that can receive the cylindrical housing 1580 described above.

Advantageously, in certain embodiments, using a daughter board 1587 to connect to the circuit board 1519 can enable connections to be made more easily to the circuit board 1519. In addition, using separate boards can be easier to manufacture than a single circuit board 1519 with all connections soldered to the circuit board 1519.

FIG. 15I illustrates an exemplary architecture for frontend interface 108 as a transimpedance-based front-end. As noted, front-end interfaces 108 provide an interface that adapts the output of detectors 106 into a form that can be handled by signal processor 110. As shown in this figure, sensor 101 and front-end interfaces 108 may be integrated together as a single component, such as an integrated circuit. Of course, one skilled in the art will recognize that sensor 101 and front end interfaces 108 may comprise multiple components or circuits that are coupled together.

Front-end interfaces 108 may be implemented using transimpedance amplifiers that are coupled to analog to digital converters in a sigma delta converter. In some embodiments, a programmable gain amplifier (PGA) can be used in combination with the transimpedance-based front-ends. For example, the output of a transimpedance-based front-end may be output to a sigma-delta ADC that comprises a PGA. A PGA may be useful in order to provide another level of amplification and control of the stream of signals from detectors 106. The PGA may be an integrated circuit or built from a set of micro-relays. Alternatively, the PGA and ADC components in converter 900 may be integrated with the transimpedance-based front-end in sensor 101.

Due to the low-noise requirements for measuring blood analytes like glucose and the challenge of using multiple photodiodes in detector 106, the applicants developed a noise model to assist in configuring front-end 108. Conventionally, those skilled in the art have focused on optimizing the impedance of the transimpedance amplifiers to minimize

However, the following noise model was discovered by the applicants:

Noise=
$$\sqrt{aR+bR^2}$$
, where:

aR is characteristic of the impedance of the transimpedance amplifier; and

bR<sup>2</sup> is characteristic of the impedance of the photodiodes in detector and the number of photodiodes in detector **106**.

The foregoing noise model was found to be helpful at least in part due to the high SNR required to measure analytes like glucose. However, the foregoing noise model was not previously recognized by artisans at least in part because, in conventional devices, the major contributor to noise was generally believed to originate from the emitter or the LEDs. Therefore, artisans have generally continued to focus on reducing noise at the emitter.

However, for analytes like glucose, the discovered noise model revealed that one of the major contributors to noise was generated by the photodiodes. In addition, the amount of noise varied based on the number of photodiodes coupled to a transimpedance amplifier. Accordingly, combinations of various photodiodes from different manufacturers, different impedance values with the transimpedance amplifiers, and different numbers of photodiodes were tested as possible embodiments.

In some embodiments, different combinations of transimpedance to photodiodes may be used. For example, detectors 1-4 (as shown, e.g., in FIG. 12A) may each comprise four photodiodes. In some embodiments, each detector of four

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photodiodes may be coupled to one or more transimpedance amplifiers. The configuration of these amplifiers may be set according to the model shown in FIG. **15**J.

Alternatively, each of the photodiodes may be coupled to its own respective transimpedance amplifier. For example, 5 transimpedance amplifiers may be implemented as integrated circuits on the same circuit board as detectors 1-4. In this embodiment, the transimpedance amplifiers may be grouped into an averaging (or summing) circuit, which are known to those skilled in the art, in order to provide an 10 output stream from the detector. The use of a summing amplifier to combine outputs from several transimpedance amplifiers into a single, analog signal may be helpful in improving the SNR relative to what is obtainable from a single transimpedance amplifier. The configuration of the 15 transimpedance amplifiers in this setting may also be set according to the model shown in FIG. 15J.

As yet another alternative, as noted above with respect to FIGS. 12E through 12H, the photodiodes in detectors 106 may comprise multiple active areas that are grouped 20 together. In some embodiments, each of these active areas may be provided its own respective transimpedance. This form of pairing may allow a transimpedance amplifier to be better matched to the characteristics of its corresponding photodiode or active area of a photodiode.

As noted, FIG. **15**J illustrates an exemplary noise model that may be useful in configuring transimpedance amplifiers. As shown, for a given number of photodiodes and a desired SNR, an optimal impedance value for a transimpedance amplifier could be determined.

For example, an exemplary "4 PD per stream" sensor 1502 is shown where detector 106 comprises four photodiodes 1502. The photodiodes 1502 are coupled to a single transimpedance amplifier 1504 to produce an output stream 1506. In this example, the transimpedance amplifier comprises 10 M $\Omega$  resistors 1508 and 1510. Thus, output stream 1506 is produced from the four photodiodes (PD) 1502. As shown in the graph of FIG. 15J, the model indicates that resistance values of about 10 M $\Omega$  may provide an acceptable SNR for analytes like glucose.

However, as a comparison, an exemplary "1 PD per stream" sensor 1512 is also shown in FIG. 15J. In particular, sensor 1512 may comprise a plurality of detectors 106 that each comprises a single photodiode 1514. In addition, as shown for this example configuration, each of photodiodes 45 1514 may be coupled to respective transimpedance amplifiers 1516, e.g., 1 PD per stream. Transimpedance amplifiers are shown having 40 M $\Omega$  resistors 1518. As also shown in the graph of FIG. 15J, the model illustrates that resistance values of 40 M $\Omega$  for resistors 1518 may serve as an 50 alternative to the 4 photodiode per stream architecture of sensor 1502 described above and yet still provide an equivalent SND

Moreover, the discovered noise model also indicates that utilizing a 1 photodiode per stream architecture like that in 55 sensor 1512 may provide enhanced performance because each of transimpedance amplifiers 1516 can be tuned or optimized to its respective photodiodes 1518. In some embodiments, an averaging component 1520 may also be used to help cancel or reduce noise across photodiodes 1518.

For purposes of illustration, FIG. 15K shows different architectures (e.g., four PD per stream and one PD per stream) for various embodiments of a sensor and how components of the sensor may be laid out on a circuit board or substrate. For example, sensor 1522 may comprise a "4 PD per stream" architecture on a submount 700 in which each detector 106 comprises four (4) photodiodes 1524. As

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shown for sensor 1522, the output of each set of four photodiodes 1524 is then aggregated into a single transimpedance amplifier 1526 to produce a signal.

As another example, a sensor 1528 may comprise a "1 PD per stream" architecture on submount 700 in which each detector 106 comprises four (4) photodiodes 1530. In sensor 1528, each individual photodiode 1530 is coupled to a respective transimpedance amplifier 1532. The output of the amplifiers 1532 may then be aggregated into averaging circuit 1520 to produce a signal.

As noted previously, one skilled in the art will recognize that the photodiodes and detectors may be arranged in different fashions to optimize the detected light. For example, sensor 1534 illustrates an exemplary "4 PD per stream" sensor in which the detectors 106 comprise photodiodes 1536 arranged in a linear fashion. Likewise, sensor 1538 illustrates an exemplary "1 PD per stream" sensor in which the detectors comprise photodiodes 1540 arranged in a linear fashion.

Alternatively, sensor 1542 illustrates an exemplary "4 PD per stream" sensor in which the detectors 106 comprise photodiodes 1544 arranged in a two-dimensional pattern, such as a zig-zag pattern. Sensor 1546 illustrates an exemplary "1 PD per stream" sensor in which the detectors comprise photodiodes 1548 also arranged in a zig-zag pattern.

FIG. 15L illustrates an exemplary architecture for a switched-capacitor-based front-end. As shown, front-end interfaces 108 may be implemented using switched capacitor circuits and any number of front-end interfaces 108 may be implemented. The output of these switched capacitor circuits may then be provided to a digital interface 1000 and signal processor 110. Switched capacitor circuits may be useful in system 100 for their resistor free design and analog averaging properties. In particular, the switched capacitor circuitry provides for analog averaging of the signal that allows for a lower smaller sampling rate (e.g., 2 KHz sampling for analog versus 48 KHz sampling for digital designs) than similar digital designs. In some embodiments, the switched capacitor architecture in front end interfaces 108 may provide a similar or equivalent SNR to other front end designs, such as a sigma delta architecture. In addition, a switched capacitor design in front end interfaces 108 may require less computational power by signal processor 110 to perform the same amount of decimation to obtain the same SNR.

FIGS. 16A and 16B illustrate embodiments of disposable optical sensors 1600. In an embodiment, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be incorporated into the disposable sensors 1600 shown. For instance, the sensors 1600 can be used as the sensors 101 in the system 100 described above with respect to FIG. 1. Moreover, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be implemented in other disposable sensor designs that are not depicted herein.

The sensors 1600 include an adult/pediatric sensor 1610 for finger placement and a disposable infant/neonate sensor 1602 configured for toe, foot or hand placement. Each sensor 1600 has a tape end 1610 and an opposite connector end 1620 electrically and mechanically interconnected via a flexible coupling 1630. The tape end 1610 attaches an emitter and detector to a tissue site. Although not shown, the tape end 1610 can also include any of the protrusion, shielding, and/or heat sink features described above. The emitter illuminates the tissue site and the detector generates

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a sensor signal responsive to the light after tissue absorption, such as absorption by pulsatile arterial blood flow within the tissue site.

The sensor signal is communicated via the flexible coupling 1630 to the connector end 1620. The connector end 1620 can mate with a cable (not shown) that communicates the sensor signal to a monitor (not shown), such as any of the cables or monitors shown above with respect to FIGS. 2A through 2D. Alternatively, the connector end 1620 can mate directly with the monitor.

FIG. 17 illustrates an exploded view of certain of the components of the sensor 301f described above. A heat sink 1751 and a cable 1781 attach to an emitter shell 1704. The emitter shell attaches to a flap housing 1707. The flap housing 1707 includes a receptacle 1709 to receive a cylindrical housing 1480/1580 (not shown) attached to an emitter submount 1702, which is attached to a circuit board 1719.

A spring 1787 attaches to a detector shell 1706 via pins 1783, 1785, which hold the emitter and detector shells 1704, 20 1706 together. A support structure 1791 attaches to the detector shell 1706, which provides support for a shielding enclosure 1790. A noise shield 1713 attaches to the shielding enclosure 1790. A detector submount 1700 is disposed inside the shielding enclosure 1790. A finger bed 1710 25 provides a surface for placement of the patient's finger. Finger bed 1710 may comprise a gripping surface or gripping features, which may assist in placing and stabilizing a patient's finger in the sensor. A partially cylindrical protrusion 1705 may also be disposed in the finger bed 1710. As 30 shown, finger bed 1710 attaches to the noise shield 1703. The noise shield 1703 may be configured to reduce noise, such as from ambient light and electromagnetic noise. For example, the noise shield 1703 may be constructed from materials having an opaque color, such as black or a dark 35 blue, to prevent light piping.

Noise shield 1703 may also comprise a thermistor 1712. The thermistor 1712 may be helpful in measuring the temperature of a patient's finger. For example, the thermistor 1712 may be useful in detecting when the patient's finger is 40 reaching an unsafe temperature that is too hot or too cold. In addition, the temperature of the patient's finger may be useful in indicating to the sensor the presence of low perfusion as the temperature drops. In addition, the thermistor 1712 may be useful in detecting a shift in the characteristics of the water spectrum in the patient's finger, which can be temperature dependent.

Moreover, a flex circuit cover 1706 attaches to the pins 1783, 1785. Although not shown, a flex circuit can also be provided that connects the circuit board 1719 with the 50 submount 1700 (or a circuit board to which the submount 1700 is connected). A flex circuit protector 1760 may be provided to provide a barrier or shield to the flex circuit (not shown). In particular, the flex circuit protector 1760 may also prevent any electrostatic discharge to or from the flex circuit. The flex circuit protector 1760 may be constructed from well known materials, such as a plastic or rubber materials.

FIG. 18 shows the results obtained by an exemplary sensor 101 of the present disclosure that was configured for 60 measuring glucose. This sensor 101 was tested using a pure water ex-vivo sample. In particular, ten samples were prepared that ranged from 0-55 mg/dL. Two samples were used as a training set and eight samples were then used as a test population. As shown, embodiments of the sensor 101 were 65 able to obtain at least a standard deviation of 13 mg/dL in the training set and 11 mg/dL in the test population.

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FIG. 19 shows the results obtained by an exemplary sensor 101 of the present disclosure that was configured for measuring glucose. This sensor 101 was tested using a turbid ex-vivo sample. In particular, 25 samples of water/glucose/Liposyn were prepared that ranged from 0-55 mg/dL. Five samples were used as a training set and 20 samples were then used as a test population. As shown, embodiments of sensor 101 were able to obtain at least a standard deviation of 37 mg/dL in the training set and 32 mg/dL in the test population.

FIGS. 20 through 22 shows other results that can be obtained by an embodiment of system 100. In FIG. 20, 150 blood samples from two diabetic adult volunteers were collected over a 10-day period. Invasive measurements were taken with a YSI glucometer to serve as a reference measurement. Noninvasive measurements were then taken with an embodiment of system 100 that comprised four LEDs and four independent detector streams. As shown, the system 100 obtained a correlation of about 85% and Arms of about 31 mg/dL.

In FIG. 21, 34 blood samples were taken from a diabetic adult volunteer collected over a 2-day period. Invasive measurements were also taken with a glucometer for comparison. Noninvasive measurements were then taken with an embodiment of system 100 that comprised four LEDs in emitter 104 and four independent detector streams from detectors 106. As shown, the system 100 was able to attain a correlation of about 90% and Arms of about 22 mg/dL.

The results shown in FIG. 22 relate to total hemoglobin testing with an exemplary sensor 101 of the present disclosure. In particular, 47 blood samples were collected from nine adult volunteers. Invasive measurements were then taken with a CO-oximeter for comparison. Noninvasive measurements were taken with an embodiment of system 100 that comprised four LEDs in emitter 104 and four independent detector channels from detectors 106. Measurements were averaged over 1 minute. As shown, the testing resulted in a correlation of about 93% and Arms of about 0.8 mg/dL.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

While certain embodiments of the inventions disclosed herein have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions disclosed herein. Indeed, the novel methods and systems described herein can be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein can be made without departing from the spirit of the inventions disclosed herein. The claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of certain of the inventions disclosed herein.

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What is claimed is:

1. A physiological measurement system comprising:

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- a physiological sensor device comprising:
  - one or more emitters configured to emit light into tissue of a user:
  - a first set of photodiodes, wherein:
    - the first set of photodiodes comprises at least four photodiodes,
    - the photodiodes of the first set of photodiodes are connected to one another in parallel to provide a first signal stream, and
    - each of the photodiodes of the first set of photodiodes has a corresponding window that allows light to pass through to the photodiode;
  - a second set of photodiodes, wherein:
    - the second set of photodiodes comprises at least four photodiodes,
    - the photodiodes of the second set of photodiodes are connected to one another in parallel to provide a 20 second signal stream, and
    - each of the photodiodes of the second set of photodiodes has a corresponding window that allows light to pass through to the photodiode;
  - a wall that surrounds at least the first and second sets of 25 photodiodes; and
  - a cover comprising a protruding convex surface, wherein the protruding convex surface is above all of the photodiodes of the first and second sets of photodiodes, wherein at least a portion of the protruding convex surface is rigid, and wherein the cover is above the wall; and
- a handheld computing device in wireless communication with the physiological sensor device, wherein the handheld computing device comprises:
  - one or more processors configured to wirelessly receive one or more signals from the physiological sensor device, the one or more signals responsive to at least a physiological parameter of the user;
  - a touch-screen display configured to provide a user 40 interface, wherein:
    - the user interface is configured to display indicia responsive to measurements of the physiological parameter, and
    - an orientation of the user interface is configurable 45 responsive to a user input; and
  - a storage device configured to at least temporarily store at least the measurements of the physiological parameter.
- 2. The physiological measurement system of claim 1, 50 wherein the physiological sensor device further comprises: preprocessing electronics configured to preprocess at least one of the first signal stream or the second signal stream.
- 3. The physiological measurement system of claim 2, 55 wherein the preprocessing comprises adapting the at least one of the first signal stream or the second signal stream.
- **4.** The physiological measurement system of claim **3**, wherein the preprocessing further comprises amplifying the at least one of the first signal stream or the second signal 60 stream.
- 5. The physiological measurement system of claim 4, wherein the preprocessing further comprises converting the at least one of the first signal stream or the second signal stream from analog to digital.
- 6. The physiological measurement system of claim 2, wherein the preprocessing electronics comprise at least:

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- a first amplifier configured to receive the first signal stream from the first set of photodiodes at an input of the first amplifier and at least amplify the first signal stream, and
- a second amplifier configured to receive the second signal stream from the second set of photodiodes at an input of the second amplifier and at least amplify the second signal stream.
- 7. The physiological measurement system of claim 6, wherein the protruding convex surface is configured to be located between tissue of the user and the photodiodes of the first and second sets of photodiodes when the physiological measurement device is worn by the user, and wherein at least part of the protruding convex surface is light permeable to allow light to reach at least one of the photodiodes of the first or second sets of photodiodes.
- 8. The physiological measurement system of claim 7, wherein the physiological sensor device further comprises: an at least partially opaque layer blocking one or more optical paths to at least one of the photodiodes of the first set of photodiodes or the second set of photodiodes, wherein the at least partially opaque layer comprises the windows that allow light to pass through to the corresponding photodiodes.
- 9. The physiological measurement system of claim 8, wherein the physiological sensor device further comprises: a substrate having a first surface, wherein the photodiodes of the first set of photodiodes and the photodiodes of the second set of photodiodes are arranged on the first surface.
- 10. The physiological measurement system of claim 9, wherein:
  - the wall surrounds at least the first set of photodiodes and the second set of photodiodes on the first surface,
  - the wall operably connects to the substrate on one side of the wall, and
  - the wall operably connects to the cover on an opposing side of the wall.
- 11. The physiological measurement system of claim 10, wherein a surface of the handheld computing device positions the touch-screen display.
- 12. The physiological measurement system of claim 11, wherein the physiological parameter comprises at least one of: pulse rate, glucose, oxygen, oxygen saturation, methemoglobin, total hemoglobin, carboxyhemoglobin, or carbon monoxide.
- 13. The physiological measurement system of claim 12, wherein the protruding convex surface protrudes a height between 1 millimeter and 3 millimeters.
- 14. The physiological measurement system of claim 12, wherein at least one of the photodiodes is configured to receive light that has been attenuated by tissue of the user.
- 15. The physiological measurement system of claim 14, wherein a portion of the physiological sensor device comprises one of at least two sizes, the two sizes intended to be appropriate for larger users and smaller users.
- 16. The physiological measurement system of claim 14, wherein at least the photodiodes of the first set of photodiodes are arranged such that a first photodiode and a second photodiode of the first set of photodiodes are arranged across from each other on opposite sides of a central point along a first axis, and a third photodiode and a fourth photodiode of the first set of photodiodes are arranged across from each other on opposite sides of the central point along a second axis which is different from the first axis.

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- 17. The physiological measurement system of claim 14, wherein the protruding convex surface protrudes a height greater than 2 millimeters and less than 3 millimeters.
- **18**. The physiological measurement system of claim **17**, wherein the attenuated light is reflected by the tissue.
- 19. The physiological measurement system of claim 1, wherein the handheld computing device comprises a mobile phone.
  - **20**. A physiological measurement system comprising: a physiological sensor device comprising:
    - one or more emitters configured to emit light into tissue of a user:
    - a first set of photodiodes, the first set of photodiodes comprising at least four photodiodes, the photodiodes of the first set of photodiodes connected to one another in parallel to provide a first signal stream; wherein each of the photodiodes of the first set of photodiodes has a corresponding window that allows light to pass through to the photodiode;
    - a second set of photodiodes, the second set of photodiodes comprising at least four photodiodes, the photodiodes of the second set of photodiodes connected to one another in parallel to provide a second signal stream, wherein each of the photodiodes of the second set of photodiodes has a corresponding window that allows light to pass through to the photodiode; and
    - a protruding convex surface, wherein the protruding convex surface is positioned such that the protruding 30 convex surface is located between tissue of the user and the photodiodes of the first and second sets of photodiodes when the physiological sensor device is worn by the user; and
  - a handheld computing device in wireless communication 35 with the physiological sensor device.
- 21. The physiological measurement system of claim 20, wherein the handheld computing device comprises a mobile phone.
- **22**. The physiological measurement system of claim **20** 40 further comprising:

preprocessing electronics comprising at least:

- a first amplifier configured to receive the first signal stream at an input of the first amplifier and at least amplify the first signal stream, and
- a second amplifier configured to receive the second signal stream at an input of the second amplifier and at least amplify the second signal stream.
- 23. The physiological measurement system of claim 22, wherein the preprocessing electronics are further configured 50 to convert at least one of the first signal stream or the second signal stream from analog to digital.
- 24. The physiological measurement system of claim 23, wherein the handheld computing device comprises:
  - one or more processors configured to wirelessly receive 55 one or more signals from the physiological sensor device, the one or more signals responsive to at least a physiological parameter of the user;
  - a touch-screen display configured to provide a user interface, wherein the user interface is configured to display 60 indicia responsive to measurements of the physiological parameter; and
  - a storage device configured to at least temporarily store at least the measurements of the physiological parameter.
- **25**. The physiological measurement system of claim **24**, 65 wherein at least part of the protruding convex surface is light permeable to allow light to reach at least one of the photo-

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diodes of the first or second sets of photodiodes, and wherein the physiological sensor device further comprises:

- an at least partially opaque layer blocking one or more optical paths to at least one of the photodiodes of the first set of photodiodes and at least one of the photodiodes of the second set of photodiodes, wherein the at least partially opaque layer comprises the windows that allow light to pass through to the corresponding photodiodes.
- 26. The physiological measurement system of claim 25, wherein the physiological sensor device further comprises: a wall that surrounds at least the first and second sets of

photodiodes; and

- a substrate having a first surface, wherein the photodiodes of the first set of photodiodes and the photodiodes of the second set of photodiodes are arranged on the first surface, wherein the wall surrounds at least the first set of photodiodes and the second set of photodiodes on the first surface; and
- a cover comprising the protruding convex surface, wherein:
  - the wall operably connects to the substrate on one side of the wall, and
  - the wall operably connects to the cover on an opposing side of the wall.
- 27. The physiological measurement system of claim 26, wherein a surface of the handheld computing device positions the touch-screen display.
- 28. The physiological measurement system of claim 27, wherein the physiological parameter comprises at least one of: pulse rate, glucose, oxygen, oxygen saturation, methemoglobin, total hemoglobin, carboxyhemoglobin, carbon monoxide, or a state or trend of wellness of the user.
- 29. The physiological measurement system of claim 28, wherein the protruding convex surface protrudes a height greater than 2 millimeters and less than 3 millimeters.
  - 30. A physiological measurement system comprising:
  - a physiological sensor device comprising:
     one or more emitters configured to emit light into tissue of a user;
    - a substrate having a first surface;
    - a first set of photodiodes arranged on the first surface, wherein:
      - the first set of photodiodes comprises at least four photodiodes,
      - the photodiodes of the first set of photodiodes are connected to one another in parallel to provide a first signal stream, and
      - each of the photodiodes of the first set of photodiodes has a corresponding window that allows light to pass through to the photodiode;
    - a second set of photodiodes arranged on the first surface, wherein:
      - the second set of photodiodes comprises at least four photodiodes,
      - the photodiodes of the second set of photodiodes are connected to one another in parallel to provide a second signal stream, and
      - each of the photodiodes of the second set of photodiodes has a corresponding window that allows light to pass through to the photodiode;
    - a cover comprising a protruding convex surface, wherein:
      - the protruding convex surface is above all of the photodiodes of the first and second sets of photodiodes.

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at least a portion of the protruding convex surface is rigid,

the cover is above the wall, and

the protruding convex surface is configured to be located between tissue of the user and the photodiodes of the first and second sets of photodiodes when the physiological measurement device is worn by the user;

a wall that surrounds at least the first and second sets of photodiodes on the first surface, wherein:

the wall operably connects to the substrate on one side of the wall, and

the wall operably connects to the cover on an opposing side of the wall; and

preprocessing electronics configured to preprocess at least one of the first signal stream or the second signal stream, wherein the preprocessing electronics comprise at least:

a first amplifier configured to receive the first signal 20 stream from the first set of photodiodes at an input of the first amplifier and at least amplify the first signal stream, and

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a second amplifier configured to receive the second signal stream from the second set of photodiodes at an input of the second amplifier and at least amplify the second signal stream; and

a handheld computing device in wireless communication with the physiological sensor device, wherein the handheld computing device comprises:

one or more processors configured to wirelessly receive one or more signals from the physiological sensor device, the one or more signals responsive to at least a physiological parameter of the user, wherein the physiological parameter comprises at least one of: pulse rate, glucose, oxygen, oxygen saturation, methemoglobin, total hemoglobin, carboxyhemoglobin, or carbon monoxide;

a touch-screen display configured to provide a user interface, wherein the user interface is configured to display indicia responsive to measurements of the physiological parameter; and

a storage device configured to at least temporarily store at least the measurements of the physiological parameter.

\* \* \* \* \*

Case: 22-1972



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# (12) United States Patent

Poeze et al.

(10) Patent No.: US 10,702,195 B1

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### (54) MULTI-STREAM DATA COLLECTION SYSTEM FOR NONINVASIVE MEASUREMENT OF BLOOD CONSTITUENTS

(71) Applicant: Masimo Corporation, Irvine, CA (US)

(72) Inventors: Jeroen Poeze, Rancho Santa Margarita, CA (US); Marcelo Lamego, Cupertino, CA (US); Sean Merritt, Lake Forest, CA (US); Cristiano Dalvi, Lake Forest, CA (US); Hung Vo, Fountain Valley, CA (US); Johannes Bruinsma, Opeinde (NL); Ferdyan Lesmana, Irvine, CA (US); Massi Joe E. Kiani, Laguna Niguel, CA (US); Greg Olsen,

Lake Forest, CA (US)

(73) Assignee: Masimo Corporation, Irvine, CA (US)

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#### (58) Field of Classification Search

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#### (56) References Cited

#### U.S. PATENT DOCUMENTS

3,910,701 A 10/1975 Henderson et al. 4,114,604 A 9/1978 Shaw et al. (Continued)

### FOREIGN PATENT DOCUMENTS

CN 1270793 A 10/2000 CN 101564290 B 10/2009 (Continued)

### OTHER PUBLICATIONS

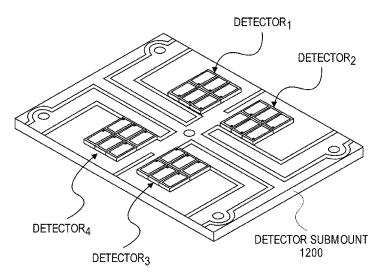
US 8,845,543 B2, 09/2014, Diab et al. (withdrawn) (Continued)

Primary Examiner — Eric F Winakur Assistant Examiner — Chu Chuan Liu (74) Attorney, Agent, or Firm — Knobbe Martens Olson & Bear LLP

### (57) ABSTRACT

The present disclosure relates to noninvasive methods, devices, and systems for measuring various blood constituents or analytes, such as glucose. In an embodiment, a light source comprises LEDs and super-luminescent LEDs. The light source emits light at at least wavelengths of about 1610 nm, about 1640 nm, and about 1665 nm. In an embodiment, the detector comprises a plurality of photodetectors arranged in a special geometry comprising one of a substantially linear substantially equal spaced geometry, a substantially linear substantially non-equal spaced geometry, and a substantially grid geometry.

# 17 Claims, 65 Drawing Sheets



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4,825,872 A

5/1989 Tan et al.

### Related U.S. Application Data

continuation of application No. 16/534,949, filed on Aug. 7, 2019, now Pat. No. 10,588,553, which is a continuation of application No. 16/409,515, filed on May 10, 2019, now Pat. No. 10,376,191, which is a continuation of application No. 16/261,326, filed on Jan. 29, 2019, now Pat. No. 10,292,628, which is a continuation of application No. 16/212,537, filed on Dec. 6, 2018, now Pat. No. 10,258,266, which is a continuation of application No. 14/981,290, filed on Dec. 28, 2015, now Pat. No. 10,335,068, which is a continuation of application No. 12/829,352, filed on Jul. 1, 2010, now Pat. No. 9,277,880, which is a continuation of application No. 12/534,827, filed on Aug. 3, 2009, now abandoned, and a continuationin-part of application No. 12/497,528, filed on Jul. 2, 2009, now Pat. No. 8,577,431, which is a continuation-in-part of application No. 29/323,408, filed on Aug. 25, 2008, now Pat. No. Des. 606,659, and a continuation-in-part of application No. 29/323,409, filed on Aug. 25, 2008, now Pat. No. Des. 621,516, said application No. 12/829,352 is a continuation-inpart of application No. 12/497,523, filed on Jul. 2, 2009, now Pat. No. 8,437,825, which is a continuation-in-part of application No. 29/323,408, filed on Aug. 25, 2008, now Pat. No. Des. 606,659, and a continuation-in-part of application No. 29/323,409, filed on Aug. 25, 2008, now Pat. No. Des. 621,516.

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See application file for complete search history.

### (56) References Cited

#### U.S. PATENT DOCUMENTS

4,258,719 A 4,267,844 A	3/1981 5/1981	Lewyn Yamanishi
4,438,338 A 4,444,471 A 4,653,498 A	3/1984 4/1984 3/1987	Stitt Ford et al. New, Jr. et al.
4,655,225 A 4,684,245 A	4/1987 8/1987	Dahne et al.
4,709,413 A 4,755,676 A 4,781,195 A	11/1987 7/1988 11/1988	Forrest Gaalema et al. Martin
4,805,623 A	2/1989	

4,880,304 A	11/1989	Jaeb et al.
4,960,128 A	10/1990	Gordon et al.
4,964,408 A	10/1990	Hink et al.
5,028,787 A	7/1991	Rosenthal et al.
5,035,243 A	7/1991	Muz
5,041,187 A	8/1991	Hink et al.
5,043,820 A	8/1991	Wyles et al.
5,069,213 A	12/1991	Polczynski
5,069,214 A	12/1991	Samaras et al.
5,077,476 A 5,086,229 A	12/1991 2/1992	Rosenthal
5,080,229 A 5,099,842 A	3/1992	Rosenthal et al. Mannheimer et al.
D326,715 S	6/1992	Schmidt
5,122,925 A	6/1992	Inpyn
5,131,391 A	7/1992	Sakai et al.
5,137,023 A	8/1992	Mendelson et al.
5,158,091 A	10/1992	Butterfiled et al.
5,159,929 A	11/1992	McMillen et al.
5,163,438 A	11/1992	Gordon et al.
5,203,329 A	4/1993	Takatani et al.
5,222,295 A	6/1993	Dorris, Jr.
5,222,495 A	6/1993	Clarke et al.
5,222,496 A	6/1993	Clarke et al.
5,228,449 A	7/1993	Christ et al.
5,249,576 A	10/1993	Goldberger et al.
5,250,342 A 5,278,627 A	10/1993 1/1994	Lang Aoyagi et al.
5,297,548 A	3/1994	Pologe
5,319,355 A	6/1994	Russek
5,333,616 A	8/1994	Mills et al.
5,337,744 A	8/1994	Branigan
5,337,745 A	8/1994	Benaron
5,341,805 A	8/1994	Stavridi et al.
5,355,242 A	10/1994	Eastmond et al.
5,358,519 A	10/1994	Grandjean
5,362,966 A	11/1994	Rosenthal et al.
D353,195 S	12/1994	Savage et al.
D353,196 S	12/1994	Savage et al.
5,377,676 A	1/1995	Vari et al.
D356,870 S D359,546 S	3/1995	Ivers et al.
D359,546 S 5,427,093 A	6/1995 6/1995	Savage et al. Ogawa et al.
5,431,170 A	7/1995	Mathews
D361,840 S	8/1995	Savage et al.
5,437,275 A	8/1995	Amundsen et al.
5,441,054 A	8/1995	Tsuchiya
D362,063 S	9/1995	Savage et al.
5,452,717 A	9/1995	Branigan et al.
D363,120 S	10/1995	Savage et al.
5,456,252 A	10/1995	Vari et al.
5,462,051 A	10/1995	Oka et al.
5,479,934 A 5,482,034 A	1/1996 1/1996	Imran Lewis et al.
5,482,034 A 5,482,036 A	1/1996	Diab et al.
5,490,505 A	2/1996	Diab et al.
5,490,506 A	2/1996	Takatani et al.
5,490,523 A	2/1996	Isaacson et al.
5,494,043 A	2/1996	O'Sullivan et al.
5,497,771 A	3/1996	Rosenheimer
5,511,546 A	4/1996	Hon
5,533,511 A	7/1996	Kaspari et al.
5,534,851 A	7/1996	Russek
5,551,422 A	9/1996	Simonsen et al.
5,553,615 A	9/1996	Carim et al.
5,553,616 A 5,561,275 A	9/1996 10/1996	Ham et al.
5,562,002 A	10/1996	Savage et al. Lalin
5,564,429 A	10/1996	Bornn et al.
5,584,296 A	12/1996	Cui et al.
5,590,649 A	1/1997	Caro et al.
5,601,079 A	2/1997	Wong et al.
5,602,924 A	2/1997	Durand et al.
D378,414 S		Allen et al.
	3/1997	
	3/1997 4/1997	Swenson et al.
5,623,925 A	4/1997	
5,623,925 A		Swenson et al.
5,623,925 A 5,625,458 A	4/1997 4/1997	Swenson et al. Alfano et al. Diab et al.
5,623,925 A 5,625,458 A 5,632,272 A	4/1997 4/1997 5/1997	Swenson et al. Alfano et al.

(56)	Referen	ces Cited		,241,680		6/2001	
IJ	S. PATENT	DOCUMENTS		,241,683 ,241,684			MacKlem et al. Amano et al.
Ü		Docomer (10		,253,097			Aronow et al.
5,645,440 A		Tobler et al.		,256,523			Diab et al.
5,676,143 A		Simonsen et al.  Diab et al.		,263,222			Diab et al. Lepper, Jr. et al.
5,685,299 A 5,687,717 A		Halpern et al.		,278,889			Robinson
5,699,808 A				,280,213		8/2001	Tobler et al.
D390,666 S		Lagerlof		,285,896			Tobler et al. Mottahed
5,729,203 <i>A</i> D393,830 S		Oka et al. Tobler et al.		,301,493			Marro et al.
5,743,262 A		Lepper, Jr. et al.	6	,308,089	B1		von der Ruhr et al.
5,750,927 A	5/1998	Baltazar		,317,627		11/2001 11/2001	Ennen et al.
5,752,914 A 5,758,644 A		Delonzor et al. Diab et al.		,321,100 0452,012		12/2001	
5,760,910 A		Lepper, Jr. et al.	6	,325,761	B1	12/2001	Jay
5,766,131 A	A 6/1998	Kondo et al.		,334,065			Al-Ali et al.
5,769,785 A		Diab et al. Diab et al.		,343,223		1/2002	Chin et al. Parker
5,782,757 A 5,785,659 A		Caro et al.		,345,194		2/2002	Nelson et al.
5,791,347 A	8/1998	Flaherty et al.		,349,228			Kiani et al.
5,792,052 A		Isaacson et al.		,353,750 ,356,203			Kimura et al. Halleck et al.
5,795,300 A 5,800,349 A		Isaacson et al.		,360,113			Dettling
5,807,247 A		Merchant et al.		,360,114			Diab et al.
5,810,734 A		Caro et al.		,360,115			Greenwald et al. Donars et al.
5,823,950 A 5,826,885 A		Diab et al. Helgeland		,368,283			Xu et al.
5,830,131 A	11/1998	Caro et al.	6	,371,921	B1		Caro et al.
5,830,137 A	11/1998	Scharf		,377,829		4/2002	
5,833,618 A		Caro et al.		,388,240			Schulz et al. Diab et al.
D403,070 S 5,851,178 A		Maeda et al. Aronow		,430,437		8/2002	
5,860,919 A		Kiani-Azarbayjany et al.		,430,525			Weber et al.
5,890,929 A		Mills et al.		0463,561 ,463,187			Fukatsu et al. Baruch et al.
5,902,235 A 5,903,357 A		Lewis et al.		,463,311		10/2002	
5,904,654 A		Wohltmann et al.		,470,199			Kopotic et al.
5,919,134 A				,470,893 ,475,153		10/2002	Boesen Khair et al.
5,934,925 <i>A</i> 5,940,182 <i>A</i>		Tobler et al. Lepper, Jr. et al.		E37,922		12/2002	
5,957,840 A		Terasawa et al.	6	,491,647	B1		Bridger et al.
D414,870 S	5 10/1999	Saltzstein et al.		,501,975 ,505,059			Diab et al. Kollias et al.
5,987,343 <i>A</i> 5,995,855 <i>A</i>		Kinast Kiani et al.		,515,273		2/2003	
5,997,343 A		Mills et al.	6	,516,289	B2		David et al.
6,002,952 A	12/1999	Diab et al.		,519,487		2/2003	Parker Mizuno et al.
6,011,986 <i>A</i> 6,018,673 <i>A</i>		Diab et al. Chin et al.		,522,521 ,525,386			Mills et al.
6,027,452 A	A 2/2000	Flaherty et al.		,526,300		2/2003	Kiani et al.
6,036,642 A	3/2000	Diab et al.		,541,756			Schulz et al.
6,045,509 A		Caro et al.		,542,764 ,556,852			Al-Ali et al. Schulze et al.
6,049,727 A 6,067,462 A		Crothall Diab et al.		,580,086		6/2003	Schulz et al.
6,081,735 A	A 6/2000	Diab et al.		,584,336			Ali et al.
6,088,607 A		Diab et al.		,595,316 ,597,932			Cybulski et al. Tian et al.
6,102,856 A 6,110,522 A		Groff et al. Lepper, Jr. et al.	6	,597,933	B2		Kiani et al.
6,124,597 A	A 9/2000	Shehada		,606,509			Schmitt
6,128,521 A		Marro et al.		,606,511 0481,459		8/2003 10/2003	Ali et al.
6,129,675 <i>A</i> 6,144,866 <i>A</i>		Miesel et al.		,632,181	B2	10/2003	Flaherty et al.
6,144,868 A	11/2000			,636,759			Robinson
6,151,516 A		Kiani-Azarbayjany et al.		,639,668		10/2003 10/2003	Trepagnier Shim
6,152,754 A 6,157,850 A		Gerhardt et al. Diab et al.		,640,116		10/2003	
6,165,005 A		Mills et al.		,643,530			Diab et al.
6,167,258 A		Schmidt et al.		,650,917 ,650,939			Diab et al. Takpke, II et al.
6,172,743 E 6,175,752 E		Kley et al. Say et al.		,654,624			Diab et al.
6,181,958 E		Steuer et al.		,658,276			Kiani et al.
6,184,521 E	31 2/2001	Coffin, IV et al.	6	,661,161	B1	12/2003	Lanzo et al.
6,202,930 E				,668,185		12/2003	
6,206,830 E 6,223,063 E		Diab et al. Chaiken et al.		,671,526 ,671,531			Aoyagi et al. Al-Ali et al.
6,229,856 E		Diab et al.	6	,678,543	B2		Diab et al.
6,232,609 E	5/2001	Snyder et al.	6	,681,133	B2	1/2004	Chaiken et al.
6,236,872 E	5/2001	Diab et al.	6	,684,090	B2	1/2004	Ali et al.

(56)	Referen	ces Cited	7,149,561 B2 D535,031 S	12/2006	Diab Barrett et al.
U.S.	PATENT	DOCUMENTS	D537,164 S	2/2007	
0.0.		DOCUMENTS.	7,186,966 B2	3/2007	Al-Ali
6,684,091 B2	1/2004		7,190,261 B2	3/2007	
6,697,656 B1	2/2004		7,215,984 B2 7,215,986 B2	5/2007 5/2007	
6,697,657 B1 6,697,658 B2	2/2004 2/2004	Shehada et al.	7,221,971 B2	5/2007	
RE38,476 E		Diab et al.	7,225,006 B2		Al-Ali et al.
6,699,194 B1		Diab et al.	7,225,007 B2	5/2007	
6,714,804 B2		Al-Ali et al.	RE39,672 E		Shehada et al.
RE38,492 E		Diab et al.	7,227,156 B2 7,230,227 B2		Colvin, Jr. et al. Wilcken et al.
6,721,582 B2 6,721,585 B1	4/2004	Trepagnier et al.	D547,454 S	7/2007	
6,725,075 B2	4/2004		7,239,905 B2		Kiani-Azarbayjany et al.
6,728,560 B2		Kollias et al.	7,245,953 B1	7/2007	
6,735,459 B2	5/2004		D549,830 S 7,254,429 B2		Behar et al. Schurman et al.
6,745,060 B2 6,748,254 B2		Diab et al. O'Neil et al.	7,254,431 B2	8/2007	
6,760,607 B2	7/2004		7,254,433 B2		Diab et al.
6,770,028 B1		Ali et al.	7,254,434 B2		Schulz et al.
6,771,994 B2		Kiani et al.	D550,364 S D551,350 S		Glover et al. Lorimer et al.
6,785,568 B2 6,792,300 B1		Chance Diab et al.	7,272,425 B2	9/2007	
6,801,799 B2		Mendelson	7,274,955 B2		Kiani et al.
6,811,535 B2	11/2004	Palti et al.	D553,248 S	10/2007	
6,813,511 B2		Diab et al.	D554,263 S 7,280,858 B2	10/2007	Al-Ali et al.
6,816,010 B2 6,816,241 B2		Seetharaman et al. Grubisic et al.	7,289,835 B2		Mansfield et al.
6,816,741 B2	11/2004		7,292,883 B2		De Felice et al.
6,822,564 B2	11/2004		7,295,866 B2	11/2007	
6,826,419 B2		Diab et al.	D562,985 S 7,328,053 B1		Brefka et al. Diab et al.
6,830,711 B2 6,831,266 B2		Mills et al. Paritsky et al.	7,332,784 B2		Mills et al.
6,850,787 B2		Weber et al.	7,340,287 B2		Mason et al.
6,850,788 B2	2/2005		7,341,559 B2		Schulz et al.
6,852,083 B2		Caro et al.	7,343,186 B2 D566,282 S		Lamego et al. Al-Ali et al.
D502,655 S	3/2005 3/2005		D567,125 S		Okabe et al.
6,861,639 B2 6,897,788 B2		Khair et al.	7,355,512 B1	4/2008	
6,898,452 B2		Al-Ali et al.	7,356,365 B2		Schurman
6,912,413 B2		Rantala et al.	7,365,923 B2 D569,001 S	4/2008 5/2008	Hargis et al.
6,920,345 B2		Al-Ali et al.	D569,521 S	5/2008	
D508,862 S 6,931,268 B1		Behar et al. Kiani-Azarbayjany et al.	7,371,981 B2		Abdul-Hafiz
6,934,570 B2	8/2005	Kiani et al.	7,373,193 B2		Al-Ali et al.
6,939,305 B2		Flaherty et al.	7,373,194 B2 7,376,453 B1		Weber et al. Diab et al.
6,943,348 B1		Coffin, IV	7,377,794 B2		Al Ali et al.
6,950,687 B2 D510,625 S	9/2005	Widener et al.	7,377,899 B2		Weber et al.
6,961,598 B2	11/2005		7,383,070 B2		Diab et al.
6,970,792 B1	11/2005		7,395,189 B2 7,415,297 B2		Qing et al. Al-Ali et al.
6,979,812 B2	1/2005		7,413,297 B2 7,428,432 B2		Ali et al.
6,985,764 B2 6,993,371 B2		Mason et al. Kiani et al.	7,438,683 B2		Al-Ali et al.
D514,461 S	2/2006		7,440,787 B2	10/2008	
6,995,400 B2		Mizuyoshi	7,454,240 B2 7,467,002 B2		Diab et al. Weber et al.
6,996,427 B2 6,999,904 B2		Ali et al. Weber et al.	7,469,157 B2		Diab et al.
7,003,338 B2		Weber et al.	7,471,969 B2		Diab et al.
7,003,339 B2	2/2006	Diab et al.	7,471,971 B2	12/2008	Diab et al.
7,015,451 B2		Dalke et al.	7,483,729 B2 7,483,730 B2		Al-Ali et al. Diab et al.
7,024,233 B2 7,026,619 B2		Ali et al. Cranford	7,489,958 B2		Diab et al.
7,020,019 B2 7,027,849 B2	4/2006		7,496,391 B2		Diab et al.
7,030,749 B2	4/2006		7,496,393 B2		Diab et al.
7,039,449 B2	5/2006		D587,657 S 7,499,741 B2		Al-Ali et al. Diab et al.
7,041,060 B2 7,044,918 B2	5/2006	Flaherty et al.	7,499,835 B2		Weber et al.
7,044,918 B2 7,047,054 B2	5/2006		7,500,950 B2	3/2009	
7,048,687 B1	5/2006	Reuss et al.	7,509,153 B2		Blank et al.
7,060,963 B2		Maegawa et al.	7,509,154 B2		Diab et al.
7,067,893 B2 7,092,757 B2		Mills et al. Larson et al.	7,509,494 B2 7,510,849 B2	3/2009	Al-Alı Schurman et al.
7,096,052 B2		Mason et al.	7,510,849 B2 7,519,327 B2	4/2009	
7,096,054 B2		Abdul-Hafiz et al.	7,526,328 B2		Diab et al.
7,113,815 B2	9/2006	O'Neil et al.	7,530,942 B1	5/2009	Diab
7,132,641 B2		Schulz et al.	7,530,949 B2		Al Ali et al.
7,142,901 B2	11/2006	Kiani et al.	7,530,955 B2	5/2009	Diab et al.

Case: 22-1972 Document: 33-2 Page: 219 Filed: 05/11/2023

(56)	Referen	ces Cited	8,071,935 B2		Besko et al.
U.S.	PATENT	DOCUMENTS	RE43,169 E 8,118,620 B2	2/2012 2/2012	Al-Ali et al.
0.0.		D G C G I I I I I I I I I I I I I I I I I	8,126,528 B2		Diab et al.
7,563,110 B2		Al-Ali et al.	8,126,531 B2 8,128,572 B2		Crowley Diab et al.
7,596,398 B2 7,601,123 B2		Al-Ali et al. Tweed et al.	8,130,105 B2		Al-Ali et al.
7,606,606 B2		Laakkonen	8,145,287 B2	3/2012	Diab et al.
D603,966 S		Jones et al.	8,150,487 B2		Diab et al.
7,613,490 B2 7,618,375 B2	11/2009		8,175,672 B2 8,180,420 B2	5/2012 5/2012	Diab et al.
D606,659 S		Flaherty Kiani et al.	8,182,443 B1	5/2012	Kiani
7,647,083 B2	1/2010	Al-Ali et al.	8,185,180 B2		Diab et al.
D609,193 S		Al-Ali et al.	8,190,223 B2 8,190,227 B2		Al-Ali et al. Diab et al.
7,657,294 B2 7,657,295 B2		Eghbal et al. Coakley et al.	8,203,438 B2		Kiani et al.
7,657,296 B2	2/2010	Raridan et al.	8,203,704 B2		Merritt et al.
D614,305 S RE41,317 E		Al-Ali et al. Parker	8,204,566 B2 8,219,170 B2		Schurman et al. Hausmann et al.
7,726,209 B2		Ruotoistenmaki	8,219,172 B2		Schurman et al.
7,729,733 B2	6/2010	Al-Ali et al.	8,224,411 B2		Al-Ali et al.
7,734,320 B2	6/2010		8,228,181 B2 8,229,532 B2	7/2012 7/2012	
7,740,588 B1 7,740,589 B2		Sciarra Maschke et al.	8,229,533 B2		Diab et al.
7,761,127 B2		Al-Ali et al.	8,233,955 B2		Al-Ali et al.
7,761,128 B2		Al-Ali et al.	8,244,325 B2 8,244,326 B2		Al-Ali et al. Ninomiya et al.
7,764,982 B2 D621,516 S		Dalke et al. Kiani et al.	8,255,026 B1	8/2012	
7,791,155 B2	9/2010	Diab	8,255,027 B2		Al-Ali et al.
7,801,581 B2	9/2010		8,255,028 B2 8,260,577 B2		Al-Ali et al. Weber et al.
7,809,418 B2 7,822,452 B2	10/2010 10/2010	Schurman et al.	8,265,723 B1		McHale et al.
RE41,912 E	11/2010	Parker	8,274,360 B2		Sampath et al.
7,844,313 B2		Kiani et al.	8,280,473 B2 8,289,130 B2	10/2012	Nakajima et al.
7,844,314 B2 7,844,315 B2	11/2010 11/2010		8,301,217 B2		Al-Ali et al.
7,862,523 B2		Ruotoistenmaki	8,306,596 B2		Schurman et al.
7,865,222 B2		Weber et al.	8,310,336 B2 8,315,683 B2		Muhsin et al. Al-Ali et al.
7,869,849 B2 7,873,497 B2		Ollerdessen et al. Weber et al.	RE43,860 E	12/2012	
7,880,606 B2	2/2011		8,280,469 B2		Baker, Jr.
7,880,626 B2		Al-Ali et al.	8,332,006 B2 8,337,403 B2		Naganuma et al. Al-Ali et al.
7,884,314 B2 7,891,355 B2		Hamada Al-Ali et al.	8,346,330 B2		Lamego
7,894,868 B2		Al-Ali et al.	8,353,842 B2		Al-Ali et al.
7,899,506 B2		Xu et al.	8,355,766 B2 8,359,080 B2		MacNeish, III et al. Diab et al.
7,899,507 B2 7,899,510 B2		Al-Ali et al. Hoarau	8,364,223 B2		Al-Ali et al.
7,899,518 B2		Trepagnier et al.	8,364,226 B2		Diab et al.
7,904,132 B2		Weber et al.	8,364,389 B2 8,374,665 B2		Dorogusker et al. Lamego
7,909,772 B2 7,910,875 B2		Popov et al. Al-Ali	8,380,272 B2		Barrett et al.
7,919,713 B2	4/2011	Al-Ali et al.	8,385,995 B2		Al-ali et al.
7,937,128 B2 7,937,129 B2		Al-Ali Mason et al.	8,385,996 B2 8,388,353 B2		Smith et al. Kiani et al.
7,937,129 B2 7,937,130 B2		Diab et al.	8,399,822 B2	3/2013	
7,941,199 B2	5/2011	Kiani	8,401,602 B2	3/2013	
7,951,086 B2 7,957,780 B2		Flaherty et al. Lamego et al.	8,405,608 B2 8,414,499 B2		Al-Ali et al. Al-Ali et al.
7,962,188 B2		Kiani et al.	8,418,524 B2	4/2013	Al-Ali
7,962,190 B1	6/2011	Diab et al.	8,421,022 B2 8,423,106 B2		Rozenfeld
7,976,472 B2 7,988,637 B2	7/2011 8/2011		8,428,674 B2		Lamego et al. Duffy et al.
7,988,037 B2 7,990,382 B2	8/2011		8,428,967 B2	4/2013	Olsen et al.
7,991,446 B2	8/2011	Ali et al.	8,430,817 B1 8,437,825 B2		Al-Ali et al. Dalvi et al.
8,000,761 B2 8,008,088 B2		Al-Ali Bellott et al.	8,452,364 B2		Hannula et al.
RE42,753 E		Kiani-Azarbayjany et al.	8,455,290 B2	6/2013	Siskavich
8,019,400 B2	9/2011	Diab et al.	8,457,703 B2 8,457,707 B2	6/2013 6/2013	
8,028,701 B2 8,029,765 B2		Al-Ali et al. Bellott et al.	8,463,349 B2		Diab et al.
8,036,727 B2		Schurman et al.	8,466,286 B2		Bellot et al.
8,036,728 B2	10/2011	Diab et al.	8,471,713 B2		Poeze et al.
8,044,998 B2		Heenan	8,473,020 B2 8,483,787 B2		Kiani et al. Al-Ali et al.
8,046,040 B2 8,046,041 B2		Ali et al. Diab et al.	8,483,787 B2 8,489,364 B2		Weber et al.
8,046,042 B2		Diab et al.	8,496,595 B2		Jornod
8,048,040 B2	11/2011		8,498,684 B2		Weber et al.
8,050,728 B2	11/2011	Al-Ali et al.	8,504,128 B2	8/2013	Blank et al.

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U.S. PATENT DOCUMENTS  8.821,478 132 9.2014 Al-Ali et al. 8.821,478 132 9.2014 Al-Ali et al. 8.821,478 132 9.2014 Al-Ali et al. 8.831,509 182 9.2013 Mintenna et al. 8.841,509 182 9.2014 McKenna et al. 8.841,509 182 9.2014 McKenna et al. 8.845,518 182 9.2013 McKenna et al. 8.842,749 182 9.2014 Al-Ali et al. 8.842,309 182 9.2013 Al-Ali et al. 8.842,749 182 9.2014 McKenna et al. 8.842,749 182 10.2013 McKenna et al. 8.842,848 182 10.2013 McKenna et al. 8.842,848 182 10.2013 McKenna et al. 8.842,848 182 10.2013 McKenna et al. 8.842,849 182 10.2013 McKenna et al. 8.842,840 18	(56)	Referen	ces Cited	8,801,613			Al-Ali et al.
8,599,867 B2 82013 Workman et al. 8,831,700 B2 92014 Schurman et al. 8,815,515 B2 82013 McKenan et al. 8,840,540 B2 92014 Al-Ali et al. 8,852,040 B2 102014 Al-Ali et al. 8,852,040 B2 102014 Al-Ali et al. 8,852,040 B2 102015 Al-Ali et al. 8,852,040 B2 10	U.S.	PATENT	DOCUMENTS	8,821,415	B2	9/2014	Al-Ali et al.
8.515.599 B2 82013 B0ninsme et al.  8.8305.798 B2 92013 Al-Ali et al.  8.825.788 B2 92013 Al-Ali et al.  8.825.788 B2 92013 Al-Ali et al.  8.825.788 B2 92013 Al-Ali et al.  8.825.798 B2 92013 Al-Ali et al.  8.825.799 B2 10.2014 Similar et al.  8.825.799 B2 10.2013 Al-Ali et al.  8.826.710 B2 10.2013 Similar et al.  8.826.710 B2 10.2013 Similar et al.  8.826.710 B2 10.2013 Similar et al.  8.826.710 B2 10.2013 Al-Ali et al.  8.827.810 B2 10.2013 Al-Ali et al.  8.827.810 B2 10.2013 Al-Ali et al.  8.827.161 B3 10.2015 Al-Ali et	0.500.065 P2	0/2012	XX 1 1				
8.515,515 B2 82013 McKenan et al.  8.527,818 B2 92013 Al-All et al.  8.527,818 B2 92013 Al-All et al.  8.527,818 B2 92013 Al-All et al.  8.527,918 B2 92013 Al-All et al.  8.527,919 B2 102014 Al-All et al.  8.527,919 B2 102014 Al-All et al.  8.527,919 B2 102015 Al-All et al.  8.527,1619 B2 102015				8,838,210	B2	9/2014	Wood et al.
8.529.301 B2 9.2013 Al-Ali et al. 8.529.301 B2 9.2014 Al-Ali et al. 8.529.302 B2 9.2013 Diab et al. 8.529.303 B2 9.2013 Diab et al. 8.529.304 B2 10.2014 Al-Ali et al. 8.529.304 B2 10.2014 Al-Ali et al. 8.529.305 B2 10.2014 Al-Ali et al. 8.529.305 B2 10.2015 Al-Ali et al. 8.529.305 B2 10.2014 Al-Ali et al. 8.529.305 B2 10.2015 Al-Ali et al. 8.529.305 B2 10.2015 Al-Ali et al. 8.529.305 B2 10.2015 Al-Ali et al. 8.529.307 B2 11.2014 Al-Ali et al. 8.529.307 B2 11.2014 Al-Ali et al. 8.529.308 B2 11.2015 Al-Ali et al. 8.529.309 B2 11.2015 Al-Ali et al. 8.529.309 B2 11.2015 Al-	8,515,515 B2						
8, 532,727 B2 92013 Ai et al. \$852,094 B2 102014 AVAI et al. \$852,094 B2 102015 AVAI et al. \$852,094 B2 102016 AVAI et al. \$852,094 B2 102016 AVAI et al. \$852,094 B2 102016 AVAI et al. \$852,094 B2 102017 AVAI et al. \$852,094 B2 102018 Aignet et al. \$852,094 B2 102018 AVAI et al. \$852,094 B2 102018 AVAI et al. \$852,095 B2 102014 AVAI et al. \$852,095 B2 102018 AVAI et al. \$852,095 B2 102018 AVAI et al. \$852,095 B2 102014 AVAI et al. \$852,095 B2 102018 AVAI et al.				8,849,365	B2		
Devol. 145   S   10/2013   Al-Ali et al.	8,532,727 B2	9/2013	Ali et al.				
8,474,209 B2   10/2013   Kiani et al.   8,808,159 B2   10/2014   Al-Ali et al.   8,709,229 B2   10/2014   Al-Ali et al.   8,709,220 B2   10/2014   Al-Ali et al.   8,709,220 B2   10/2014   Al-Ali et al.   8,809,320 B2   10/2014   Al-Ali et al.   8,809,320 B2   10/2014   Al-Ali et al.   8,809,320 B2   10/2014   Al-Ali et al.   8,909,310 B2   10/2015   Diab et al.   8,909,310 B2   10/2015							
8,548,549 B2 10,2013 Schumman et al. 8,548,559 B2 10,2013 Al-Ali et al. 8,550,032 B2 10,2013 Al-Ali et al. 8,550,033 B1 10,2013 Al-Ali et al. 8,550,031 B1 10,2013 Al-Ali et al. 8,550,031 B1 10,2013 Al-Ali et al. 8,550,031 B2 10,2013 Al-Ali et al. 8,570,167 B2 10,2013 Al-Ali et al. 8,570,167 B2 10,2013 Al-Ali et al. 8,570,167 B2 10,2013 Al-Ali et al. 8,571,617 B2 10,2013 Al-Ali et al. 8,571,617 B2 10,2013 Al-Ali et al. 8,571,619 B2 1	8,547,209 B2	10/2013	Kiani et al.				
8,548,550 B2 10/2013 Al-Ali et al. 8,888,359 B2 11/2014 Al-Ali et al. 8,886,0034 B1 10/2013 Diab et al. 8,887,008 B2 11/2014 Diab et al. 8,887,008 B2 11/2014 Diab et al. 8,887,008 B2 11/2014 Al-Ali et al. 8,870,503 B2 10/2013 Vo 8,909,310 B2 12/2014 Al-Ali et al. 8,971,619 B2 10/2013 Vo 8,909,310 B2 12/2014 Al-Ali et al. 8,971,619 B2 10/2013 Lamego et al. 8,912,909 B2 12/2014 Al-Ali et al. 8,971,619 B2 10/2013 Al-Ali et al. 8,971,619 B2 10/2014 Al-Ali et al. 8,971,619 B2 10/2013 Al-Ali et al. 8,971,619 B2 10/2013 Diab 8,606,342 B2 10/2013 Diab 8,965,471 B2 20/2015 Diab et al. 8,971,619 B2 10/2015 Diab et al. 8,971,619 B2 10/2015 Diab 8,606,342 B2 10/2014 Al-Ali et al. 8,973,646 B2 3/2015 Al-Ali et al. 8,971,619 B2 10/2015 Diab 8,606,342 B2 10/2014 Al-Ali et al. 8,973,646 B2 3/2015 Al-Ali et al. 8,973,740 B2 10/2015 Diab 8 Al-Ali et							
8,556,034 B1   10,2013 Diab et al.   8,892,189 B2   11/2014   Weber et al.   8,570,503 B2   12/2014   Al-Ali   8,570,503 B2   12/2013   Al-Ali   8,570,503 B2   12/2014   Al-Ali   8,571,618 B1   10,2013   Reichgott et al.   8,912,309 B2   12/2014   Al-Ali et al.   8,571,618 B1   10,2013   Al-Ali et al.   8,920,313 B2   12/2014   Al-Ali et al.   8,571,618 B2   11/2013   Al-Ali et al.   8,920,313 B2   12/2014   Al-Ali et al.   8,571,618 B2   11/2013   Al-Ali et al.   8,920,313 B2   12/2014   Al-Ali et al.   8,571,638 B2   11/2013   Al-Ali et al.   8,920,313 B2   12/2014   Al-Ali et al.   8,581,328 B2   11/2013   Al-Ali et al.   8,920,332 B2   12/2014   Al-Ali et al.   8,581,328 B2   11/2013   Al-Ali et al.   8,922,338 B2   12/2014   Al-Ali et al.   8,922,338 B2   12/2013   Al-Ali et al.   8,922,338 B2   12/2014   Al-Ali et al.   8,922,338 B2   12/2013   Al-Ali et al.   8,922,338 B2   12/2014   Al-Ali et al.   8,922,338 B2   12/2014   Al-Ali et al.   8,963,471 B2   12/2015   Al-Ali et al.   8,963,471 B2   12/2014   Al-Ali et al.   8,963,471 B2   12/2015   Al-Ali et al.   8,963,471 B2   12/2014   Al-Ali et al.   8,963,473 B2   3/2015   Al-Ali et al.   8,664,638 B2   12/2014   Al-Ali et al.   8,998,809 B2   4/2015   Al-Ali et al.   8,655,206 B2   2/2014   Al-Ali et al.   8,998,809 B2   4/2015   Al-Ali et al.   8,655,206 B2   2/2014   Al-Ali et al.   9,066,638 B1   2/2014   Al-Ali et al.   9,066,638 B1   2/2015   Al-Al	8,548,550 B2	10/2013	Al-Ali et al.				
8,570,167 B2 10,2013 Al-Ali							
8,571,617 B2 102013 Reichgott et al. 8,571,618 B1 102013 Lamego et al. 8,571,619 B2 102013 Al-Ali et al. 8,571,631 B2 112013 Lamego et al. 8,571,631 B2 112013 Al-Ali et al. 8,571,632 B2 112013 Al-Ali et al. 8,602,632 B2 122013 Diab 8,965,471 B2 22015 Diab et al. 8,602,632 B2 122013 Diab 8,965,471 B2 22015 Diab et al. 8,632,632 B3 122014 Al-Ali et al. 8,633,633 B3 123014 Al-Ali				8,897,847	B2	11/2014	Al-Ali
8,571,618 Bi 10,2013 Lamego et al. 8,912,909 B2 12,2014 Al-Ali et al. 8,571,431 B2 11/2013 Al-Ali et al. 8,920,317 B2 12/2014 Hong et al. 8,571,431 B2 11/2013 Al-Ali et al. 8,920,317 B2 12/2014 Hong et al. 8,581,323 B2 11/2013 Al-Ali et al. 8,921,539 B2 12/2014 Al-Ali et al. 8,581,323 B2 11/2013 Al-Ali et al. 8,921,538 B2 12/2014 Al-Ali et al. 8,581,343 B2 11/2013 Al-Ali et al. 8,922,946 B2 12/2014 Al-Ali et al. 8,581,343 B2 11/2013 Al-Ali et al. 8,923,947 B2 12/2014 Al-Ali et al. 8,581,342 B2 12/2013 Al-Ali et al. 8,948,343 B2 2/2015 Diab et al. 8,600,476 B2 12/2013 Al-Ali et al. 8,948,343 B2 2/2015 Diab et al. 8,600,476 B2 12/2013 Diab 8,665,342 B2 12/2013 Diab 8,665,471 B2 2/2015 Diab 8,615,290 B2 12/2013 Diab 8,665,342 B2 12/2013 Diab 8,665,342 B2 12/2013 Lin et al. 8,988,531 B2 2/2015 Diab 8,615,290 B2 12/2014 Al-Ali et al. 8,988,546 B2 3/2015 Al-Ali et al. 8,634,889 B2 1/2014 Al-Ali et al. 8,988,546 B2 3/2015 Al-Ali et al. 8,634,889 B2 1/2014 Al-Ali et al. 8,998,809 B2 2/2015 Kiani et al. 8,655,004 B2 2/2014 Al-Ali et al. 8,998,809 B2 2/2015 Kiani et al. 8,655,004 B2 2/2014 Al-Ali et al. 9,058,479 B2 5/2015 Telfort et al. 8,655,004 B2 2/2014 Al-Ali et al. 9,058,671 B2 5/2015 Al-Ali et al. 8,667,676 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,667,676 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,667,967 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali et al. 9,066,666 B2 6/2015 Kiani et al. 8,670,814 B2 3/2014 Al-Ali e							
8,577,431 B2   11/2013   Lanego et al.   8,920,332 B2   12/2014   Hong et al.   8,581,343 B2   12/2013   Al-Ali et al.   8,921,699 B2   12/2014   Al-Ali et al.   8,581,345 B2   11/2013   Al-Ali et al.   8,922,964 B2   12/2014   Al-Ali et al.   8,583,385 B2   11/2013   Adolt-Hafiz et al.   8,929,964 B2   12/2015   Diab et al.   8,604,676 B2   12/2013   Al-Ali et al.   8,948,734 B2   12/2015   Diab et al.   8,604,676 B2   12/2013   Al-Ali et al.   8,948,873 B2   2/2015   Diab et al.   8,602,971 B2   12/2013   Diab   8,665,702 B2   12/2014   Al-Ali et al.   8,988,503 B2   2/2015   Al-Ali et al.   8,988,803 B2   2/2015   Al-Ali et al.   8,988,803 B2   2/2014   Al-Ali et al.   8,998,809 B2   2/2015   Al-Ali et al.   8,665,706 B2   2/2014   Al-Ali et al.   8,998,809 B2   2/2015   Kiani et al.   8,655,006 B2   2/2014   Al-Ali et al.   8,998,809 B2   2/2015   Kiani et al.   8,655,006 B2   2/2014   Al-Ali et al.   9,037,207 B2   5/2015   Al-Ali et al.   8,665,408 B2   2/2014   Al-Ali et al.   9,007,207 B2   5/2015   Al-Ali et al.   8,665,408 B2   2/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,665,408 B2   2/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,665,408 B2   2/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,418 B2   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,418 B2   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,418 B2   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,418 B2   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,418 B2   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,418 B2   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,488 B1   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.   8,666,488 B1   3/2014   Al-Ali et al.   9,006,666 B2   6/2015   Al-Ali et al.				8,912,909	B2	12/2014	Al-Ali et al.
8,581,732 B2 11/2013 Al-Ali et al. 8,521,828 B2 12/2014 Al-Ali et al. 8,523,838 B2 11/2013 Al-Ali et al. 8,523,838 B3 B2 11/2013 Al-Ali et al. 8,523,838 B3 B2 11/2013 Al-Ali et al. 8,501,426 B2 11/2013 Al-Ali et al. 8,501,426 B2 11/2013 Al-Ali et al. 8,600,467 B2 12/2013 Al-Ali et al. 8,600,467 B2 12/2013 Ja-Ali et al. 8,600,467 B2 12/2013 Ja-Ali et al. 8,600,467 B2 12/2013 Ja-Ali et al. 8,600,477 B2 12/2013 Diab 8,866,471 B2 2/2015 Diab et al. 8,600,478 B2 12/2013 Ja-Ali et al. 8,600,478 B2 12/2013 Ja-Ali et al. 8,600,478 B2 12/2013 Ja-Ali et al. 8,600,678 B2 12/2014 Al-Ali et al. 8,600,678 B2 12/2014 Al-Ali et al. 8,600,678 B2 12/2014 Al-Ali et al. 8,600,678 B2 2/2014 Al-Ali 8,600,678 B2 2/2014 Al-Ali 8,600,678 B2 2/2014 Al-Ali 8,600,678 B2 3/2014 Al-Ali et al. 8,600,679 B2 3/2014 Al-Ali et al. 8,600,678 B2 3/2014 Al-Ali et al. 8,600,679 B2 3/2014 Al-Ali et al. 8,600,679 B2 3/2014 Al-Ali et al. 8,600,679 B2 3/2014 Al-Ali et al. 8,600,799 B2 4/2014 Al-Ali et al. 8,700,119 B2 4							
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8,760,517 B2 6/2014 Sarwar et al. 9,192,312 B2 11/2015 Al-Ali 8,761,850 B2 6/2014 Lamego 9,192,329 B2 11/2015 Al-Ali 11/2015 R764,671 B2 7/2014 Kiani 9,192,351 B1 11/2015 Telfort et al. 8,768,423 B2 7/2014 Shakespeare et al. 9,195,385 B2 11/2015 Al-Ali et al. 8,768,426 B2 7/2014 Haisley et al. 9,210,566 B2 12/2015 Ziemianska et al. 8,771,204 B2 7/2014 Telfort et al. 9,211,072 B2 12/2015 Kiani 8,777,634 B2 7/2014 Kiani et al. 9,211,095 B1 12/2015 Al-Ali et al. 8,781,543 B2 7/2014 Diab et al. 9,218,454 B2 12/2015 Kiani et al. 8,781,544 B2 7/2014 Al-Ali et al. 9,226,696 B2 1/2016 Kiani 8,781,549 B2 7/2014 Al-Ali et al. 9,241,662 B2 1/2016 Kiani 8,788,003 B2 7/2014 Schurman et al. 9,245,668 B1 1/2016 Vo et al.				9,176,141	B2	11/2015	Al-Ali et al.
8,761,850 B2 6/2014 Lamego 9,192,329 B2 11/2015 Al-Ali 8,768,423 B2 7/2014 Kiani 9,195,385 B2 11/2015 Al-Ali et al. 8,768,426 B2 7/2014 Haisley et al. 9,210,566 B2 12/2015 Ziemianska et al. 8,771,204 B2 7/2014 Telfort et al. 9,211,072 B2 12/2015 Kiani 8,776,34 B2 7/2014 Kiani et al. 9,211,095 B1 12/2015 Al-Ali et al. 8,781,543 B2 7/2014 Diab et al. 9,211,095 B1 12/2015 Kiani et al. 8,781,544 B2 7/2014 Al-Ali et al. 9,218,454 B2 12/2015 Kiani et al. 8,781,549 B2 7/2014 Al-Ali et al. 9,226,696 B2 1/2016 Kiani et al. 8,788,003 B2 7/2014 Schurman et al. 9,245,668 B1 1/2016 Vo et al.							
8,768,423 B2 7/2014 Shakespeare et al. 9,195,385 B2 11/2015 Al-Ali et al. 8,768,426 B2 7/2014 Haisley et al. 9,210,566 B2 12/2015 Ziemianska et al. 8,771,204 B2 7/2014 Telfort et al. 9,211,072 B2 12/2015 Kiani 8,777,634 B2 7/2014 Kiani et al. 9,211,095 B1 12/2015 Al-Ali 8,781,543 B2 7/2014 Diab et al. 9,218,454 B2 12/2015 Kiani et al. 8,781,544 B2 7/2014 Al-Ali et al. 9,226,696 B2 1/2016 Kiani et al. 8,781,549 B2 7/2014 Al-Ali et al. 9,241,662 B2 1/2016 Kiani et al. 8,788,003 B2 7/2014 Schurman et al. 9,245,668 B1 1/2016 Vo et al.				9,192,329	B2	11/2015	Al-Ali
8,768,426       B2       7/2014       Haisley et al.       9,210,566       B2       12/2015       Ziemianska et al.         8,771,204       B2       7/2014       Telfort et al.       9,211,072       B2       12/2015       Kiani         8,777,634       B2       7/2014       Kiani et al.       9,211,095       B1       12/2015       Al-Ali         8,781,543       B2       7/2014       Diab et al.       9,218,454       B2       12/2015       Kiani et al.         8,781,544       B2       7/2014       Al-Ali et al.       9,226,696       B2       1/2016       Kiani         8,781,549       B2       7/2014       Al-Ali et al.       9,241,662       B2       1/2016       Al-Ali et al.         8,788,003       B2       7/2014       Schurman et al.       9,245,668       B1       1/2016       Vo et al.							
8,771,204       B2       7/2014       Telfort et al.       9,211,072       B2       12/2015       Kiani         8,777,634       B2       7/2014       Kiani et al.       9,211,095       B1       12/2015       Al-Ali         8,781,543       B2       7/2014       Diab et al.       9,218,454       B2       12/2015       Kiani et al.         8,781,544       B2       7/2014       Al-Ali et al.       9,226,696       B2       1/2016       Kiani         8,781,549       B2       7/2014       Al-Ali et al.       9,241,662       B2       1/2016       Al-Ali et al.         8,788,003       B2       7/2014       Schurman et al.       9,245,668       B1       1/2016       Vo et al.						12/2015	Ziemianska et al.
8,781,543       B2       7/2014       Diab et al.       9,218,454       B2       12/2015       Kiani et al.         8,781,544       B2       7/2014       Al-Ali et al.       9,226,696       B2       1/2016       Kiani         8,781,549       B2       7/2014       Al-Ali et al.       9,241,662       B2       1/2016       Al-Ali et al.         8,788,003       B2       7/2014       Schurman et al.       9,245,668       B1       1/2016       Vo et al.	8,771,204 B2	7/2014	Telfort et al.				
8,781,544       B2       7/2014       Al-Ali et al.       9,226,696       B2       1/2016       Kiani         8,781,549       B2       7/2014       Al-Ali et al.       9,241,662       B2       1/2016       Al-Ali et al.         8,788,003       B2       7/2014       Schurman et al.       9,245,668       B1       1/2016       Vo et al.							
8,788,003 B2 7/2014 Schurman et al. 9,245,668 B1 1/2016 Vo et al.	8,781,544 B2	7/2014	Al-Ali et al.	9,226,696	B2	1/2016	Kiani

Case: 22-1972 Document: 33-2 Page: 221 Filed: 05/11/2023

(56)	References Cited		9,717,458		Lamego et al.
U.S.	PATENT DOCUME	NTS	9,723,997 9,724,016		Lamego Al-Ali et al.
			9,724,024		Al-Ali Kiani et al.
9,267,572 B2 9,277,880 B2	2/2016 Barker et al 3/2016 Poeze et al.		9,724,025 9,730,640		Diab et al.
9,289,167 B2	3/2016 Diab et al.		9,743,887		Al-Ali et al.
9,295,421 B2	3/2016 Kiani et al.		9,749,232 9,750,442		Sampath et al. Olsen
9,307,928 B1 9,311,382 B2	4/2016 Al-Ali et al. 4/2016 Varoglu et a		9,750,443	B2 9/2017	Smith et al.
9,323,894 B2	4/2016 Kiani		9,750,461 9,752,925		Telfort Chu et al.
D755,392 S 9,326,712 B1	5/2016 Hwang et al 5/2016 Kiani	•	9,775,545		Al-Ali et al.
9,333,316 B2	5/2016 Kiani		9,775,546		Diab et al.
9,339,220 B2 9,339,236 B2	5/2016 Lamego et a 5/2016 Frix et al.	1.	9,775,570 9,778,079		Al-Ali et al.
9,341,565 B2	5/2016 Lamego et a	1.	9,781,984	B2 10/2017	Baranski et al.
9,351,673 B2	5/2016 Diab et al. 5/2016 Al-Ali et al.		9,782,077 9,782,110		Lamego et al. Kiani
9,351,675 B2 9,357,665 B2	5/2016 Al-All et al. 5/2016 Myers et al.		9,787,568	B2 10/2017	Lamego et al.
9,364,181 B2	6/2016 Kiani et al.	1	9,788,735 9,788,768		Al-Ali Al-Ali et al.
9,368,671 B2 9,370,325 B2	6/2016 Wojtczuk et 6/2016 Al-Ali et al.		9,795,300		
9,370,326 B2	6/2016 McHale et a	1.	9,795,310		
9,370,335 B2 9,375,185 B2	6/2016 Al-Ali et al. 6/2016 Ali et al.		9,795,358 9,795,739		Telfort et al. Al-Ali et al.
9,386,953 B2	7/2016 Al-Ali		9,801,556		
9,386,961 B2 9,392,945 B2	7/2016 Al-Ali et al. 7/2016 Al-Ali et al.		9,801,588 9,808,188		Weber et al. Perea et al.
9,397,448 B2	7/2016 Al-Ali et al.		9,814,418	B2 11/2017	Weber et al.
9,408,542 B1	8/2016 Kinast et al.		9,820,691 9,833,152		Kiani Kiani et al.
9,436,645 B2 9,445,759 B1	9/2016 Al-Ali et al. 9/2016 Lamego et a		9,833,180	B2 12/2017	Shakespeare et al.
9,466,919 B2	10/2016 Kiani et al.		9,838,775 9,839,379		Qian et al. Al-Ali et al.
9,474,474 B2 9,480,422 B2	10/2016 Lamego et a 11/2016 Al-Ali	.1.	9,839,381		Weber et al.
9,480,435 B2	11/2016 Olsen		9,847,002		Kiani et al.
9,489,081 B2 9,492,110 B2	11/2016 Anzures et a 11/2016 Al-Ali et al.		9,847,749 9,848,800		Kiani et al. Lee et al.
9,497,534 B2	11/2016 Prest et al.		9,848,806		Al-Ali et al.
9,510,779 B2 9,517,024 B2	12/2016 Poeze et al. 12/2016 Kiani et al.		9,848,807 9,848,823		Lamego Raghuram et al.
9,526,430 B2	12/2016 Klain et al. 12/2016 Srinivas et a	1.	9,861,298	B2 1/2018	Eckerbom et al.
9,532,722 B2	1/2017 Lamego et a 1/2017 Al-Ali et al.		9,861,304 9,861,305		Al-Ali et al. Weber et al.
9,538,949 B2 9,538,980 B2	1/2017 Al-All et al.		9,866,671	B1 1/2018	Thompson et al.
9,549,696 B2	1/2017 Lamego et a		9,867,575 9,867,578		Maani et al. Al-Ali et al.
9,553,625 B2 9,554,737 B2	1/2017 Hatanaka et 1/2017 Schurman e		9,872,623	B2 1/2018	Al-Ali
9,560,996 B2	2/2017 Kiani		9,876,320 9,877,650		Coverston et al. Muhsin et al.
9,560,998 B2 9,566,019 B2	2/2017 Al-Ali et al. 2/2017 Al-Ali et al.		9,877,686		Al-Ali et al.
9,579,039 B2	2/2017 Jansen et al		9,891,079		
9,591,975 B2 9,593,969 B2	3/2017 Dalvi et al. 3/2017 King		9,891,590 9,895,107		Shim et al. Al-Ali et al.
9,622,692 B2	4/2017 Lamego et a	1.	9,898,049	B2 2/2018	Myers et al.
9,622,693 B2 D788,312 S	4/2017 Diab 5/2017 Al-Ali et al.		9,913,617 9,918,646		Al-Ali et al. Singh Alvarado et al.
9,636,055 B2	5/2017 Al-Ali et al.		9,924,893		Schurman et al.
9,636,056 B2 9,649,054 B2	5/2017 Al-Ali	1	9,924,897 9,936,917		Abdul-Hafiz Poeze et al.
9,651,405 B1	5/2017 Lamego et a 5/2017 Gowreesunk		9,943,269	B2 4/2018	Muhsin et al.
9,662,052 B2	5/2017 Al-Ali et al.		9,949,676 9,952,095		Al-Ali Hotelling et al.
9,668,676 B2 9.668,679 B2	6/2017 Culbert 6/2017 Schurman e	: al.	9,955,937	B2 5/2018	Telfort
9,668,680 B2	6/2017 Bruinsma et	al.	9,965,946 9,980,667		Al-Ali Kiani et al.
9,668,703 B2 9,675,286 B2	6/2017 Al-Ali 6/2017 Diab		D820,865	S 6/2018	Muhsin et al.
9,681,812 B2	6/2017 Presura		9,986,919		Lamego et al.
9,684,900 B2 9,687,160 B2	6/2017 Motoki et al 6/2017 Kiani	•	9,986,952 9,989,560		Dalvi et al. Poeze et al.
9,693,719 B2	7/2017 Al-Ali et al.		9,993,207	B2 6/2018	Al-Ali et al.
9,693,737 B2 9,697,928 B2	7/2017 Al-Ali 7/2017 Al-Ali et al.		10,007,758 D822,215		Al-Ali et al. Al-Ali et al.
9,699,546 B2	7/2017 Al-All et al.		D822,213		Barker et al.
9,700,249 B2	7/2017 Johnson et a	1.	10,010,276		Al-Ali et al.
9,716,937 B2 9,717,425 B2	7/2017 Qian et al. 8/2017 Kiani et al.		10,032,002 10,039,080		Kiani et al. Miller et al.
9,717,448 B2	8/2017 Frix et al.		10,039,482		Al-Ali et al.

(56)	Referen	ces Cited	10,335,068	B2 7/2019	Poeze et al.
	IIC DATENT	DOCUMENTS	10,335,072 10,342,470		Al-Ali et al. Al-Ali et al.
	U.S. TATENT	DOCUMENTS	10,342,487		
10,039,491	B2 8/2018	Thompson et al.	10,342,497		Al-Ali et al.
10,052,037	B2 8/2018	Kinast et al.	10,349,895		Telfort et al.
10,055,121		Chaudhri et al.	10,349,898 10,354,504		Al-Ali et al. Kiani et al.
10,058,275 10,064,562		Al-Ali et al.	10,357,206		Weber et al.
10,066,970		Gowreesunker et al.	10,357,209		Al-Ali
10,076,257	B2 9/2018	Lin et al.	10,366,787		Sampath et al.
10,078,052		Ness et al.	10,368,787 10,376,190		Reichgott et al. Poeze et al.
10,086,138 10,092,200		Novak, Jr. Al-Ali et al.	10,376,190		Poeze et al.
10,092,244		Chuang et al.	10,383,520		Wojtczuk et al.
10,092,249		Kiani et al.	10,383,527		Al-Ali
10,098,550	B2 10/2018	Al-Ali et al.	10,388,120		Muhsin et al.
10,098,591		Al-Ali et al.	10,390,716 10,398,320		) Shimuta ) Kiani et al.
10,098,610 D833,624		Al-Ali et al. DeJong et al.	10,398,383		van Dinther et al.
10,117,587			10,405,804		Al-Ali
10,123,726	B2 11/2018	Al-Ali et al.	10,406,445		Vock et al.
10,130,289		Al-Ali et al.	10,413,666 10,416,079	B2 9/2019 B2 9/2019	Al-Ali et al.  Magnussen et al.
10,130,291 D835,282		Schurman et al. Barker et al.	10,410,079		Al-Ali et al.
D835,282 D835,283		Barker et al.	D864,120		Forrest et al.
D835,284		Barker et al.	10,433,776		
D835,285		Barker et al.	10,441,181		
10,149,616		Al-Ali et al.	10,448,844 10,448,871		
10,154,815 10,159,412		Al-Ali et al. Lamego et al.	10,456,038		Lamego et al.
10,165,954			10,463,284		Al-Ali et al.
10,188,296		Al-Ali et al.	10,463,340		Telfort et al.
10,188,331		Kiani et al.	10,470,695 10,471,159		) Al-Ali ) Lapotko et al.
10,188,348 RE47,218		Al-Ali et al. Ali-Ali	10,478,107		Kiani et al.
RE47,244		Kiani et al.	10,503,379	B2 12/2019	Al-Ali et al.
RE47,249		Kiani et al.	10,505,311		
10,194,847			10,512,436 10,524,706		
10,194,848		Kiani et al. Waydo	10,524,700		Olsen
10,201,286 10,201,298		Al-Ali et al.	10,531,811		
10,205,272		Kiani et al.	10,531,819		Diab et al.
10,205,291		Scruggs et al.	10,531,835		
10,213,108			10,532,174 10,537,285		) Al-Ali ) Shreim et al.
10,215,698 10,219,706		Han et al.	10,542,903		
10,219,746		McHale et al.	10,548,561		
10,219,754	B1 3/2019	Lamego	10,555,678	B2 2/2020	
10,226,187		Al-Ali et al.	10,568,514 10,568,553		
10,226,576 10,231,657		Al-Ali et al.	RE47,882		
10,231,670		Blank et al.	10,575,779	B2 3/2020	Poeze et al.
10,231,676		Al-Ali et al.	10,582,886		Poeze et al.
RE47,353		Kiani et al.	10,588,518 10,588,553		) Kiani ) Poeze et al.
10,247,670 10,251,585		Ness et al. Al-Ali et al.	10,588,554		Poeze et al.
10,251,586		Lamego	10,588,556	B2 3/2020	Kiani et al.
10,255,994	B2 4/2019	Sampath et al.	10,595,747		Al-Ali et al.
10,258,265		Poeze et al.	10,608,817 10,610,138		Haider et al. Poeze et al.
10,258,266 10,265,024		Poeze et al. Lee et al.	10,617,338		Poeze et al.
10,203,024			10,624,563	B2 4/2020	Poeze et al.
10,278,626		Schurman et al.	10,624,564		Poeze et al.
10,278,648		Al-Ali et al.	10,631,765 10,638,961		) Poeze et al. ) Al-Ali
10,279,247 10,285,626		Kıanı Kestelli et al.	2002/0045836		Alkawwas
10,292,628		Poeze et al.	2002/0099279		Pfeiffer et al.
10,292,657	B2 5/2019	Abdul-Hafiz et al.	2002/0111546		Cook et al.
10,292,664		Al-Ali	2003/0036690		
10,299,708		Poeze et al.	2003/0158501 2004/0054290		Uchida et al. Chance
10,299,709 10,305,775		Perea et al. Lamego et al.	2004/0034290		
10,307,111		Muhsin et al.	2004/0133081		
10,325,681	B2 6/2019	Sampath et al.	2005/0020927	A1 1/2005	Blondeau et al.
10,327,337		Triman et al.	2005/0054940		Almen
10,327,713		Barker et al.	2005/0116820		Goldreich
10,332,630 10,335,033		Al-Ali Al-Ali	2005/0192490 2006/0005944		Yamamoto et al. Wang et al.
10,333,033	1/2019	an-An	2000/0003944	711 1/2000	mang et al.

Case: 22-1972 Document: 33-2 Page: 223 Filed: 05/11/2023

(56)	Referen	ces Cited	2013/0060147			Welch et al.
U.S.	PATENT	DOCUMENTS	2013/0085346 2013/0096405		4/2013	
			2013/0096936			Sampath et al.
2006/0009607 A1		Lutz et al.	2013/0131474 2013/0190581			Gu et al. Al-Ali et al.
2006/0020180 A1 2006/0025659 A1		Al-Ali Kiguchi et al.	2013/0197328			Diab et al.
2006/0161054 A1		Reuss et al.	2013/0204112			White et al.
2006/0182659 A1		Unlu et al.	2013/0211214 2013/0243021		8/2013 9/2013	Olsen Siskavich
2006/0253010 A1 2006/0258928 A1		Brady et al. Ortner et al.	2013/0296672			O'Neil et al.
2007/0073117 A1		Raridan	2013/0324808			Al-Ali et al.
2007/0100222 A1		Mastrototaro et al.	2013/0331670 2013/0338461		12/2013	Lamego et al.
2007/0106172 A1 2007/0149864 A1	5/2007 6/2007	Abreu Laakkonen	2014/0012100			Al-Ali et al.
2007/0208395 A1	9/2007	Leclerc et al.	2014/0034353			Al-Ali et al.
2007/0238955 A1		Tearney et al.	2014/0051953 2014/0051955			Lamego et al. Tiao et al.
2007/0249916 A1 2007/0260130 A1	10/2007	Pesach et al.	2014/0051333			Abdul-Hafiz et al.
2007/0293792 A1		Sliwa et al.	2014/0073887			Petersen et al.
2008/0004513 A1		Walker et al.	2014/0073960 2014/0077956			Rodriguez-Llorente et al. Sampath et al.
2008/0015424 A1 2008/0076980 A1		Bernreuter Hoarau	2014/007/330			Muhsin et al.
2008/0081966 A1		Debreczeny	2014/0081175			Telfort
2008/0130232 A1		Yamamoto	2014/0094667 2014/0100434			Schurman et al. Diab et al.
2008/0139908 A1 2008/0190436 A1	6/2008	Kurth Jaffe et al.	2014/0100434			Yuen et al.
2008/0120436 A1		Baker et al.	2014/0114199			Lamego et al.
2008/0221463 A1	9/2008		2014/0120564 2014/0121482			Workman et al. Merritt et al.
2009/0030327 A1 2009/0043180 A1		Chance Tschautscher et al.	2014/0121482		5/2014	
2009/0043180 A1 2009/0129102 A1		Xiao et al.	2014/0127137	A1		Bellott et al.
2009/0163775 A1		Barrett et al.	2014/0129702 2014/0135588			Lamego et al. Al-Ali et al.
2009/0177097 A1 2009/0187085 A1	7/2009 7/2009	Ma et al.	2014/0133388			Al-Ali et al.
2009/0234206 A1		Gaspard et al.	2014/0163344	A1	6/2014	
2009/0247885 A1		Suzuki et al.	2014/0163402 2014/0166076			Lamego et al. Kiani et al.
2009/0247984 A1 2009/0259114 A1		Lamego et al. Johnson et al.	2014/0100070			Ma et al.
2009/0270699 A1		Scholler et al.	2014/0171763		6/2014	
2009/0275813 A1	11/2009		2014/0180154 2014/0180160			Sierra et al. Brown et al.
2009/0275844 A1 2009/0306487 A1	11/2009	Al-Alı Crowe et al.	2014/0180100			Brown et al.
2010/0004518 A1		Vo et al.	2014/0192177			Bartula et al.
2010/0030040 A1		Poeze et al.	2014/0194709 2014/0194711		7/2014 7/2014	Al-Ali et al.
2010/0030043 A1 2010/0113948 A1	2/2010 5/2010	Yang et al.	2014/0194766			Al-Ali et al.
2010/0130841 A1		Ozawa et al.	2014/0206954			Yuen et al.
2010/0210925 A1		Holley et al.	2014/0206963 2014/0213864		7/2014 7/2014	Al-Alı Abdul-Hafiz et al.
2010/0305416 A1 2011/0001605 A1		Bedard et al. Kiani et al.	2014/0221854		8/2014	
2011/0004079 A1		Al-Ali et al.	2014/0243627			Diab et al.
2011/0004106 A1		Iwamiya et al.	2014/0266790 2014/0275808			Al-Ali et al. Poeze et al.
2011/0082711 A1 2011/0085721 A1		Poeze et al. Guyon et al.	2014/0275871			Lamego et al.
2011/0105854 A1	5/2011	Kiani et al.	2014/0275872			Merritt et al.
2011/0105865 A1		Yu et al. Welch et al.	2014/0275881 2014/0276013			Lamego et al. Muehlemann et al.
2011/0208015 A1 2011/0213212 A1		Al-Ali	2014/0276116	A1	9/2014	Takahashi et al.
2011/0230733 A1		Al-Ali	2014/0288400			Diab et al.
2011/0237911 A1 2011/0245697 A1		Lamego et al. Miettinen	2014/0296664 2014/0303520			Bruinsma et al. Telfort et al.
2011/0243097 A1 2012/0059267 A1		Lamego et al.	2014/0316217	A1	10/2014	Purdon et al.
2012/0150052 A1	6/2012	Buchheim et al.	2014/0316218			Purdon et al. Blank et al.
2012/0165629 A1 2012/0179006 A1		Merritt et al. Jansen et al.	2014/0316228 2014/0323825			Al-Ali et al.
2012/01/9000 A1 2012/0197093 A1		LeBoeuf et al.	2014/0323897	A1	10/2014	Brown et al.
2012/0197137 A1		Jeanne et al.	2014/0323898 2014/0330098			Purdon et al. Merritt et al.
2012/0209084 A1 2012/0227739 A1	8/2012 9/2012	Olsen et al.	2014/0330098			Al-Ali et al.
2012/0227739 A1 2012/0283524 A1		Kiani et al.	2014/0333440	Al	11/2014	Kiani
2012/0296178 A1	11/2012	Lamego et al.	2014/0336481			Shakespeare et al.
2012/0319816 A1 2012/0330112 A1	12/2012	Al-Alı Lamego et al.	2014/0343436 2014/0357966		11/2014	Al-Ali et al.
2012/0330112 A1 2013/0018233 A1		Cinbis et al.	2014/0337966		12/2014	
2013/0023775 A1	1/2013	Lamego et al.	2014/0378844	A1	12/2014	Fei
2013/0041591 A1		Lamego	2015/0005600			Blank et al.
2013/0045685 A1 2013/0046204 A1	2/2013 2/2013	Kiani Lamego et al.	2015/0011907 2015/0018650			Purdon et al. Al-Ali et al.
2015/0040204 AI	2,2013	Lamego ot ai.	_515,0010050		1,2013	

Case: 22-1972 Document: 33-2 Page: 224 Filed: 05/11/2023

(56)	Referen	nces Cited	2016/0378071 A1		Rothkopf
U.S.	PATENT	DOCUMENTS	2017/0007183 A1 2017/0010858 A1	1/2017	Dusan et al. Prest et al.
			2017/0014083 A1 2017/0024748 A1		Diab et al. Haider
2015/0032029 A1 2015/0065889 A1		Al-Ali et al. Gandelman et al.	2017/0024748 A1 2017/0042488 A1		Muhsin
2015/0073235 A1		Kateraas et al.	2017/0055896 A1		Al-Ali et al.
2015/0080754 A1		Purdon et al.	2017/0074897 A1 2017/0084133 A1		Mermel et al. Cardinali et al.
2015/0087936 A1 2015/0094546 A1	4/2015	Al-Ali et al. Al-Ali	2017/0086689 A1		Shui et al.
2015/0099950 A1	4/2015	Al-Ali et al.	2017/0086742 A1		Harrison-Noonan et al.
2015/0101844 A1 2015/0106121 A1		Al-Ali et al. Muhsin et al.	2017/0086743 A1 2017/0094450 A1		Bushnell et al. Tu et al.
2015/0100121 A1 2015/0119725 A1		Martin et al.	2017/0143281 A1	5/2017	
2015/0173671 A1		Paalasmaa et al.	2017/0147774 A1 2017/0164884 A1	5/2017	Kiani Culbert et al.
2015/0196249 A1 2015/0216459 A1		Brown et al. Al-Ali et al.	2017/0172435 A1		Presura
2015/0255001 A1	9/2015	Haughav et al.	2017/0172476 A1		Schilthuizen
2015/0257689 A1 2015/0281424 A1		Al-Ali et al. Vock et al.	2017/0173632 A1 2017/0196464 A1	6/2017 7/2017	Jansen et al.
2015/0318100 A1		Rothkopf et al.	2017/0196470 A1	7/2017	Lamego et al.
2015/0351697 A1		Weber et al.	2017/0202505 A1 2017/0209095 A1		Kirenko et al. Wagner et al.
2015/0351704 A1 2015/0366472 A1	12/2015	Kiani et al. Kiani	2017/0228516 A1	8/2017	Sampath et al.
2015/0366507 A1	12/2015	Blank	2017/0245790 A1		Al-Ali et al.
2015/0374298 A1 2015/0380875 A1		Al-Ali et al. Coverston et al.	2017/0248446 A1 2017/0251974 A1		Gowreesunker et al. Shreim et al.
2015/0380873 A1 2016/0000362 A1		Diab et al.	2017/0273619 A1	9/2017	Alvarado et al.
2016/0007930 A1		Weber et al.	2017/0281024 A1 2017/0293727 A1		Narasimhan et al. Klaassen et al.
2016/0019360 A1 2016/0022160 A1		Pahwa et al. Pi et al.	2017/0293727 A1 2017/0311891 A1		Kiani et al.
2016/0023245 A1		Zadesky et al.	2017/0325698 A1		Allec et al.
2016/0029932 A1		Al-Ali	2017/0325744 A1 2017/0340209 A1		Allec et al. Klaassen et al.
2016/0029933 A1 2016/0038045 A1		Al-Ali et al. Shapiro	2017/0340219 A1	11/2017	Sullivan et al.
2016/0041531 A1	2/2016	Mackie et al.	2017/0340293 A1		Al-Ali et al.
2016/0045118 A1 2016/0051157 A1	2/2016	Kiani Waydo	2017/0347885 A1 2017/0354332 A1	12/2017	Tan et al. Lamego
2016/0051157 A1 2016/0051158 A1	2/2016		2017/0354795 A1	12/2017	Blahnik et al.
2016/0051205 A1		Al-Ali et al.	2017/0358239 A1 2017/0358240 A1		Arney et al. Blahnik et al.
2016/0058302 A1 2016/0058309 A1	3/2016	Raghuram et al. Han	2017/0358240 A1 2017/0358242 A1		Thompson et al.
2016/0058310 A1	3/2016	Iijima	2017/0360306 A1		Narasimhan et al.
2016/0058312 A1 2016/0058338 A1		Han et al. Schurman et al.	2017/0366657 A1 2018/0008146 A1		Thompson et al. Al-Ali et al.
2016/0058356 A1		Raghuram et al.	2018/0014781 A1	1/2018	Clavelle et al.
2016/0058370 A1		Raghuram et al.	2018/0025287 A1 2018/0042556 A1		Mathew et al. Shahparnia et al.
2016/0066823 A1 2016/0066824 A1		Al-Ali et al. Al-Ali et al.	2018/0042550 A1 2018/0049694 A1		Singh Alvarado et al.
2016/0066879 A1	3/2016	Telfort et al.	2018/0050235 A1		Tan et al.
2016/0071392 A1 2016/0072429 A1		Hankey et al. Kiani et al.	2018/0055375 A1 2018/0055390 A1	3/2018	Martinez et al. Kiani
2016/0073967 A1	3/2016	Lamego et al.	2018/0055439 A1		Pham et al.
2016/0106367 A1		Jorov et al.	2018/0056129 A1 2018/0064381 A1		Narasimha Rao et al. Shakespeare et al.
2016/0113527 A1 2016/0143548 A1		Al-Ali et al. Al-Ali	2018/0070867 A1		Smith et al.
2016/0154950 A1	6/2016	Nakajima et al.	2018/0078151 A1		Allec et al.
2016/0157780 A1 2016/0166210 A1		Rimminen et al. Al-Ali	2018/0078182 A1 2018/0082767 A1		Chen et al. Al-Ali et al.
2016/0192869 A1		Kiani et al.	2018/0085068 A1	3/2018	Telfort
2016/0196388 A1		Lamego	2018/0087937 A1 2018/0103874 A1		Al-Ali et al. Lee et al.
2016/0197436 A1 2016/0213281 A1		Barker et al. Eckerbom et al.	2018/0103905 A1	4/2018	
2016/0213309 A1	7/2016	Sannholm et al.	2018/0110469 A1		Maani et al.
2016/0256058 A1 2016/0256082 A1		Pham et al. Ely et al.	2018/0125368 A1 2018/0125430 A1		Lamego et al. Al-Ali et al.
2016/0267238 A1	9/2016		2018/0132769 A1	5/2018	Weber et al.
2016/0270735 A1		Diab et al.	2018/0146901 A1 2018/0146902 A1		Al-Ali et al. Kiani et al.
2016/0283665 A1 2016/0287107 A1		Sampath et al. Szabados et al.	2018/0153418 A1		Sullivan et al.
2016/0287181 A1	10/2016	Han et al.	2018/0153442 A1		Eckerbom et al.
2016/0287786 A1 2016/0296173 A1	10/2016	Kiani Culbert	2018/0153446 A1 2018/0153448 A1	6/2018	Kiani Weber et al.
2016/0296173 A1 2016/0296174 A1		Isikman et al.	2018/0153448 A1 2018/0164853 A1		Myers et al.
2016/0310027 A1	10/2016	Han	2018/0168491 A1	6/2018	Al-Ali et al.
2016/0314260 A1 2016/0327984 A1	10/2016	Kiani Al-Ali et al.	2018/0184917 A1 2018/0192924 A1	7/2018 7/2018	
2016/032/984 A1 2016/0367173 A1		Dalvi et al.	2018/0192924 A1 2018/0192953 A1		Shreim et al.
2016/0378069 A1		Rothkopf	2018/0196514 A1	7/2018	Allec et al.

Case: 22-1972 Document: 33-2 Page: 225 Filed: 05/11/2023

(56)	Refere	nces Cited		2019/0325722 2019/0350506			Kiani et al. Al-Ali
	U.S. PATEN	Γ DOCUMENTS		2019/0357813			Poeze et al.
				2019/0357823			Reichgott et al.
2018/0199871 2018/0206795		Pauley et al. Al-Ali		2019/0357824 2019/0358524			Al-Ali Kiani
2018/0206/93		Telfort		2019/0365294			Poeze et al.
2018/0213583	A1 7/2018	Al-Ali		2019/0374139			Kiani et al.
2018/0214090 2018/0216370		Al-Ali et al.		2019/0374173 2019/0374713			Kiani et al. Kiani et al.
2018/0218370		Ishiguro et al. Muhsin et al.		2019/0386908	A1 12/20	019	Lamego et al.
2018/0225960	A1 8/2018	Al-Ali et al.		2019/0388039			Al-Ali
2018/0228414 2018/0238718		Shao et al.		2020/0000338 2020/0000415			Lamego et al. Barker et al.
2018/0238718		Dalvi Hotelling et al.		2020/0015716	A1 1/20	020	Poeze et al.
2018/0242853	A1 8/2018	Al-Ali		2020/0021930			Iswanto et al.
2018/0242923		Al-Ali et al.		2020/0037453 2020/0037891			Triman et al. Kiani et al.
2018/0242926 2018/0247353		Muhsin et al. Al-Ali et al.		2020/0037966	A1 2/20	020	Al-Ali
2018/0247712	A1 8/2018	Muhsin et al.		2020/0046257			Eckerbom et al.
2018/0256087		Al-Ali et al.		2020/0054253 2020/0060591			Al-Ali et al. Diab et al.
2018/0279956 2018/0285094		Waydo et al. Housel et al.		2020/0060628			Al-Ali et al.
2018/0296161		Shreim et al.		2020/0060629		020	Muhsin et al.
2018/0300919		Muhsin et al.		2020/0060869			Telfort et al.
2018/0310822 2018/0310823		Indorf et al. Al-Ali et al.		2020/0074819	A1 3/20	J2U	Muhsin et al.
2018/0317826		Muhsin		FO	REIGN PA	TEI	NT DOCUMENTS
2018/0317841		Novak, Jr.					
2018/0333055 2018/0333087		Lamego et al.	C		101484065		11/2011
2019/0000317		Muhsin et al.	C E		. 103906468 419223	A	7/2014 3/1991
2019/0015023		Monfre	Ë		0630208	A1	12/1994
2019/0029574 2019/0029578		Schurman et al. Al-Ali et al.	E		0770349	A1	5/1997
2019/0029378		Al-Ali et al.	E E		0 781 527 0880936	12	7/1997 12/1998
2019/0069813		Al-Ali	E		0922432		6/1999
2019/0076028 2019/0082979		Al-Ali et al. Al-Ali et al.	E		0985373	A1	3/2000
2019/0090760		Kinast et al.	E E		1 518 494 1526805	A 1	3/2005 5/2005
2019/0090764		Al-Ali	E		1124609		8/2006
2019/0117070 2019/0117139		Muhsin et al. Al-Ali et al.	E		1860989		12/2007
2019/0117139		Al-Ali	E E		1875213 1880666		1/2008 1/2008
2019/0117930		Al-Ali	E		2165196		3/2010
2019/0122763 2019/0133525		Sampath et al. Al-Ali et al.	E		2 277 440		1/2011
2019/0142283		Lamego et al.	G JI		2243691 . 05-325705 .		11/1991 12/1993
2019/0142344		Telfort et al.	Ji		08-185864	А	7/1996
2019/0150856 2019/0167161		Kiani et al. Al-Ali et al.	JI		09257508		10/1997
2019/0175019		Al-Ali et al.	JI JI		: 10314133 . H 1170086 .		12/1998 3/1999
2019/0192076		McHale et al.	JI		2919326		7/1999
2019/0200941 2019/0201623		Chandran et al. Kiani	JI		11235320	A	8/1999
2019/0209025		Al-Ali	JI JI		001-66990 01-087250	Δ	3/2001 4/2001
2019/0214778		Scruggs et al.	JI		02-500908		1/2002
2019/0216319 2019/0216379		Poeze et al. Al-Ali et al.	JI		03-024276		1/2003
2019/0221966		Kiani et al.	JI JI		03-508104 . 03-265444 .		3/2003 9/2003
2019/0223804		Blank et al.	JI		004329406		11/2004
2019/0231199 2019/0231241		Al-Ali et al. Al-Ali et al.	JI		005160641		6/2005
2019/0231270	A1 8/2019	Abdul-Hafiz et al.	JI JI		. 3741147 . 3741147		10/2005 2/2006
2019/0239787		Pauley et al.	JI		006102164		4/2006
2019/0239824 2019/0254578		Muhsin et al. Lamego	JI		06-177837		7/2006
2019/0261857		Al-Ali	JI JI		06-198321 3803351		8/2006 8/2006
2019/0269370		Al-Ali et al.	JI		07-389463		11/2007
2019/0274627 2019/0274635		Al-Ali et al. Al-Ali et al.	JI		007319232		12/2007
2019/02/4033		Dalvi et al.	JI JI		08-099222 . 5756752	A	4/2008 6/2015
2019/0298270	A1 10/2019	Al-Ali et al.	K		070061122 .	A	6/2007
2019/0304601			K	R .	100755079	Β1	9/2007
2019/0304605 2019/0307377		Al-Ali Perea et al.			100091592 . 993/12712	A	8/2010 7/1993
2019/0320906		Olsen			993/12/12 ) 94/23643 .	A1	10/1994
2019/0320959		Al-Ali	W	O WO 19	95/000070		1/1995
2019/0320988	A1 10/2019	Ahmed et al.	W	O WO 1	996/27325		9/1996

### US 10,702,195 B1

Page 12

#### (56)References Cited FOREIGN PATENT DOCUMENTS WO WO 1997/009923 A1 3/1997 WO 1999/000053 WO 1/1999 WO WO 1999/01704 7/1999 WO WO 1999/063883 A1 12/1999 wo WO 2000/25112 5/2000 WO WO 2000/028892 A1 5/2000 WO WO 2001/09589 2/2001 WO WO 2006/060949 A1 6/2006 WO WO 2006/079862 A2 8/2006 WO WO 2006/090371 A2 8/2006 WO WO 2006/113070 A2 10/2006 WO WO 2007/004083 A1 1/2007

#### WO WO 2008/107238 A1 9/2008 WO WO 2009/001988 A1 12/2008 WO WO 2009/137524 11/2009 WO WO 2010/003134 1/2010 WO WO 2011/069122 6/2011 WO WO 2013/030744 A1 3/2013 WO WO 2013/106607 A2 7/2013 WO WO 2013/181368 A1 12/2013 WO WO 2014/115075 A1 7/2014 WO WO 2014/149781 9/2014

WO 2014/153200 A1

WO 2014/178793 A1

WO 2014/184447 A1

WO 2015/187732 A1

WO 2016/066312 A1

WO 2014/158820

WO 2007/017266 A2

WO

WO

WO

WO

WO

WO

WO

#### OTHER PUBLICATIONS

2/2007

9/2014

10/2014

11/2014

11/2014

12/2015

5/2016

- U.S. Appl. No. 16/871,874, Physiological Measurement Devices, Systems, and Methods, filed May 11, 2020.
- Jan. 9, 2020 Complaint for (1) Patent Infringement (2) Trade Secret Misappropriation and (3) Ownership of Patents and Demand for Jury Trial, *Masimo Corporation and Cercacor Laboratories, Inc.* v. *Apple Inc.*, Case No. 8:20-cv-00048, 64 pages.
- Mar. 25, 2020 First Amended Complaint for (1) Patent Infringement (2) Trade Secret Misappropriation (3) Correction of Inventorship and (4) Ownership of Patents and Demand for Jury Trial, and including Exhibits 13-24 (Exhibits 1-12 and 25-31 comprise copies of publicly available U.S. patents and U.S. patent application publications, and are not included herein for ease of transmission), *Masimo Corporation and Cercacor Laboratories, Inc.* v. *Apple Inc.*, Case No. 8:20-cv-00048, pp. 1-94, 983-1043 (total of 156 pages). U.S. Pat. No. 9,277,880, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Mar. 8, 2016.
- Noninvasive Measurement of Blood Constituents, Mar. 8, 2016. U.S. Appl. No. 10,335,068, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Jul. 2, 2019. U.S. Appl. No. 10,258,265, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Apr. 16, 2019. U.S. Appl. No. 10,258,266, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Apr. 16, 2019. U.S. Appl. No. 10,299,708, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, May 28, 2019.
- U.S. Appl. No. 10,292,628, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, May 21, 2019.
- U.S. Appl. No. 10,376,190, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Aug. 13, 2019.
- U.S. Appl. No. 10,376,191, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Aug. 13, 2019.
- U.S. Appl. No. 10,588,553, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Mar. 17, 2020.

- U.S. Appl. No. 10,588,554, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Mar. 17, 2020.
- U.S. Appl. No. 10,610,138, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Apr. 7, 2020. U.S. Appl. No. 10,582,886, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, Mar. 10, 2020.
- U.S. Pat. No. 8,630,691, Multi-Stream Sensor Front Ends for Noninvasive Measurement of Blood Constituents, Jan. 14, 2014.
- U.S. Pat. No. 8,909,310, Multi-Stream Sensor Front Ends for Noninvasive Measurement of Blood Constituents, Dec. 9, 2014.
- U.S. Pat. No. 8,203,704, Multi-Stream Sensor for Noninvasive Measurement of Blood Constituents, Jun. 19, 2012.
- U.S. Pat. No. 8,570,503, Heat Sink for Noninvasive Medical Sensor, Oct. 29, 2013.
- U.S. Pat. No. 8,515,509, Multi-Stream Emitter for Noninvasive Measurement of Blood Constituents, Aug. 20, 2013.
- U.S. Pat. No. 8,577,431, Noise Shielding for a Noninvasive Device, Nov. 5, 2013.
- U.S. Pat. No. 9,717,425, Noise Shielding for a Noninvasive Device, Aug. 1, 2017.
- U.S. Pat. No. 8,437,825, Contoured Protrusion for Improving Spectroscopic Measurement of Blood Constituents, May 7, 2013.
- U.S. Pat. No. 9,591,975, Contoured Protrusion for Improving Spectroscopic Measurement of Blood Constituents, Mar. 14, 2017.
- U.S. Pat. No. 8,688,183, Emitter Driver for Noninvasive Patient Monitor, Apr. 1, 2014.
- U.S. Pat. No. 9,186,102, Emitter Driver for Noninvasive Patient Monitor, Nov. 17, 2015.
- U.S. Pat. No. 9,668,680, Emitter Driver for Noninvasive Patient Monitor, Jun. 6, 2017.
- D621516, Patient Monitoring Sensor, Aug. 10, 2010.
- D606659, Patient Monitor, Dec. 22, 2009.
- U.S. Appl. No. 10,448,871, Advanced Pulse Oximetry Sensor, Oct. 22, 2019.
- U.S. Appl. No. 10,470,695, Advanced Pulse Oximetry Sensor, Nov. 12, 2019.
- U.S. Appl. No. 12/534,827, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Aug. 3, 2009.
- U.S. Appl. No. 16/449,143, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Jun. 21, 2019.
- U.S. Appl. No. 16/534,956, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Aug. 7, 2019.
- U.S. Appl. No. 16/541,987, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Aug. 15, 2019.
- U.S. Appl. No. 16/725,478, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Dec. 23, 2019.
- U.S. Appl. No. 16/725,292, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Dec. 23, 2019.
- U.S. Appl. No. 16/829,510, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 25, 2020.
- U.S. Appl. No. 16/829,578, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 25, 2020.
- U.S. Appl. No. 16/829,536, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 25, 2020.
- U.S. Appl. No. 16/834,538, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 30, 2020.
- U.S. Appl. No. 16/834,533, Multi-Stream Data Collection System for Noninvasive Measurement of Blood Constituents, filed Mar. 30, 2020.
- U.S. Appl. No. 14/064,055, Multi-Stream Sensor for Noninvasive Measurement of Blood Constituents, filed Oct. 25, 2013.

### US 10,702,195 B1

Page 13

### (56) References Cited

#### OTHER PUBLICATIONS

U.S. Appl. No. 15/660,743, Noise Shielding for a Noninvasive Device, filed Jul. 26, 2017.

U.S. Appl. No. 16/805,605, Noise Shielding for a Noninvasive Device, filed Feb. 28, 2020.

U.S. Appl. No. 12/497,506, Heat Sink for Noninvasive Medical Sensor, filed Jul. 2, 2009.

U.S. Appl. No. 16/532,061, Physiological Measurement Devices, Systems, and Methods, filed Aug. 5, 2019.

U.S. Appl. No. 16/532,065, Physiological Measurement Devices, Systems, and Methods, filed Aug. 5, 2019.

U.S. Appl. No. 16/791,955, Physiological Measurement Devices, Systems, and Methods, filed Feb. 14, 2020.

U.S. Appl. No. 16/791,963, Physiological Measurement Devices, Systems, and Methods, filed Feb. 14, 2020.

U.S. Appl. No. 16/835,712, Physiological Measurement Devices, Systems, and Methods, filed Mar. 31, 2020.

U.S. Appl. No. 16/835,772, Physiological Measurement Devices, Systems, and Methods, filed Mar. 31, 2020.

PCT International Search Report, App. No. PCT/US2010/047899, Date of Actual Completion of Search: Jan. 26, 2011, 4 pages. International Search Report and Written Opinion for PCT/US2009/

International Search Report issued in Application No. PCT/US2009/052756, dated Feb. 10, 2009 in 14 pages.

049638, dated Jan. 7, 2010.

International Preliminary Report on Patentability and Written Opinion of the International Searching Authority issued in Application No. PCT US2009/049638, dated Jan. 5, 2011 in 9 pages.

International Preliminary Report on Patentability and Written Opinion of the International Searching Authority issued in Application No. PCT/US2009/052756, dated Feb. 8, 2011 in 8 pages.

International Preliminary Report on Patentability and Written Opinion for International Application No. PCT/US2016/040190, dated Jan. 2, 2018, in 7 pages.

Burritt, Mary F.; Current Analytical Approaches to Measuring Blood Analytes; vol. 36; No. 8(B); 1990.

Hall, et al., Jeffrey W.; Near-Infrared Spectrophotometry: A New Dimension in Clinical Chemistry; vol. 38; No. 9; 1992.

Kuenstner, et al., J. Todd; Measurement of Hemoglobin in Unlysed Blood by Near-Infrared Spectroscopy; vol. 48; No. 4, 1994.

Manzke, et al., B., Multi Wavelength Pulse Oximetry in the Measurement of Hemoglobin Fractions; SPIE, vol. 2676, Apr. 24, 1996. Naumenko, E. K.; Choice of Wavelengths for Stable Determination of Concentrations of Hemoglobin Derivatives from Absorption Spectra of Erythrocytes; vol. 63; No. 1; pp. 60-66 Jan.-Feb. 1996; Original article submitted Nov. 3, 1994.

Schmitt, Joseph M.; Simple Photon Diffusion Anaylsis of the Effects of Multiple Scattering on Pulse Oximetry; Mar. 14, 1991; revised Aug. 30, 1991.

Schmitt, et al., Joseph M.; Measurement of Blood Hematocrit by Dual-Wavelength near-IR Photoplethysmography; vol. 1641; 1992. Schnapp, et al., L.M.; Pulse Oximetry. Uses and Abuses.; Chest 1990; 98; 1244-1250 DOI 10.1378/Chest.98.5.1244.

http://www.masimo.com/rainbow/pronto.htm Noninvasive & Immediate Hemoglobin Testing, printed on Aug. 20, 2009.

http://www.masimo.com/pulseOximeter/Rad5.htm; Signal Extraction Pulse Oximeter, printed on Aug. 20, 2009.

http://blogderoliveira.blogspot.com/2008\_02\_01\_archive.html; Ricardo Oliveira, printed on Aug. 20, 2009.

http://www.masimo.com/rad-57/; Noninvasive Measurement of Methemoglobin, Carboxyhemoglobin and Oxyhemoglobin in the blood. Printed on Aug. 20, 2009.

http://amivital.ugr.es/blog/?tag+spo2; Monitorizacion de la hemoglobina . . . y mucho mas, printed on Aug. 20, 2009. http://www.masimo.com/spco/; Carboxyhemoglobin Noninvasive > Continuous > Immediate, printed on Aug. 20, 2009.

http://www.masimo.com/PARTNERS/WELCHALLYN.htm; Welch Allyn Expands Patient Monitor Capabilities with Masimo Pulse Oximetry Technology, printed on Aug. 20, 2009.

http://www.masimo.com/pulseOximeter/PPO.htm; Masimo Personal Pulse Oximeter, printed on Aug. 20, 2009.

http://www.masimo.com/generalFloor/system.htm; Masimo Patient SafetyNet System at a Glance, printed on Aug. 20, 2009.

http://www.masimo.com/partners/GRASEBY.htm; Graseby Medical Limited, printed on Aug. 20, 2009.

Japanese Office Action, re JP Application No. 2011-516895, dated Sep. 2, 2014, with translation.

Japanese Notice of Allowance, re JP Application No. 2011-516895, dated May 12, 2015, no translation.

European Office Action issued in application No. 10763901.5 dated Jan. 11, 2013.

European Office Action issued in application No. 10763901.5 dated Aug. 27, 2014.

European Office Action issued in application No. 10763901.5 dated Aug. 6, 2015.

European Office Action issued in Application No. 09791157.2, dated Jun. 20, 2016.

Kanukurthy et al., "Data Acquisition Unit for an Implantable Multi-Channel Optical Glucose Sensor", Electro/Information Technology Conference, Chicago, IL, USA, May 17-20, 2007, pp. 1-6. Konig et al., "Reflectance Pulse Oximetry—Principles and Obstetric Application in the Zurich System", Journal of Clinical Monitoring and Computing, vol. 14, No. 6, Aug. 1998, pp. 403-412. Smith, "The Pursuit of Noninvasive Glucose: 'Hunting the Deceitful Turkey'", 2006.

Small et al., "Data Handling Issues for Near-Infrared Glucose Measurements", http://www.ieee.org/organizations/pubs/newsletters/leos/apr98/datahandling.htm, accessed Nov. 27, 2007.

D. C. Zheng and Y. T. Zhang, "A ring-type device for the noninvasive measurement of arterial blood pressure," Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No. 03CH37439), Sep. 17-21, 2003, Cancun, pp. 3184-3187 vol. 4.

Sokwoo Rhee et al., "Artifact-Resistant Power-Efficient Design of Finger-Ring Plethysmographic Sensors," IEEE Transactions on Biomedical Engineering, Jul. 2001, pp. 795-805, vol. 48, No. 7.

L. Xu et al., "An integrated wrist-worn routine monitoring system for the elderly using BSN," 2008 5th International Summer School and Symposium on Medical Devices and Biosensors, Hong Kong, 2008, pp. 45-48.

J Kraitl et al., "An optical device to measure blood components by a photoplethysmographic method," Journal of Optics A: Pure and Applied Optics. 7, 2005, pp. S318-S324.

K. Nakajima et al., "Monitoring of heart and respiratory rates by photoplethysmography using digital filtering technique," Med. Eng. Phy. vol. 18, No. 5, pp. 365-372, 1996.

Russell Dresher, "Wearable Forehead Pulse Oximetry: Minimization of Motion and Pressure Artifacts," May 3, 2006, 93 pages.

Sonnia Maria López Silva et al., "Near-infrared transmittance pulse oximetry with laser diodes," Journal of Biomedical Optics vol. 8 No. 3, Jul. 2003, pp. 525-533.

Fabio Buttussi et al., "MOPET: A context-aware and user-adaptive wearable system for fitness training," Artificial Intelligence in Medicine 42, 2008, pp. 153-163.

Stephen A. Mascaro et al., "Photoplethysmograph Fingernail Sensors for Measuring Finger Forces Without Haptic Obstruction," IEEE Transactions on Robotics and Automation, vol. 17, No. 5, Oct. 2001, pp. 698-708.

Stephen A. Mascaro et al., "Measurement of Finger Posture and Three-Axis Fingertip Touch Force Using Fingernail Sensors," IEEE International Conference on Robotics and Automation, 2002, pp. 1-11.

Akira Sakane et al., "Estimating Arterial Wall Impedance using a Plethysmogram," IEEE 2003, pp. 580-585.

Nuria Oliver et al., "HealthGear: A Real-time Wearable System for Monitoring and Analyzing Physiological Signals," Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks 2006 IEEE, pp. 1-4.

Yuan-Hsiang Lin et al., "A wireless PDA-based physiological monitoring system for patient transport," IEEE Transactions on Information Technology in Biomedicine, vol. 8, No. 4, pp. 439-447, Dec. 2004.

### US 10,702,195 B1

Page 14

### (56) References Cited

#### OTHER PUBLICATIONS

- R. Fensli et al., "A Wireless ECG System for Continuous Event Recording and Communication to a Clinical Alarm Station," Conf Proc IEEE Eng Med Biol Soc, 2004, pp. 1-4.
- E. Higurashi et al., "An integrated laser blood flowmeter," Journal of Lightwave Technology, vol. 21, No. 3, pp. 591-595, Mar. 2003. T. Kiyokura et al., "Wearable Laser Blood Flowmeter for Ubiquitous Healthcare Service," 2007 IEEE/LEOS International Conference on Optical MEMS and Nanophotonics, Hualien, 2007, pp. 4-5. Takumi Morita et al., "Integrated Blood Flowmeter Using Micromachining Technology," Dec. 2004, pp. 77-80.
- Eiji Higurashi et al., "Hybrid integration technologies for optical micro-systems", Proc. SPIE 5604, Optomechatronic Micro/Nano Components, Devices, and Systems, Oct. 25, 2004, pp. 67-73.
- Grajales et al., "Wearable multisensor heart rate monitor," International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06), Cambridge, MA, 2006, pp. 4-157.
- N. Townsend, "Pulse Oximetry," Medical Electronics, 2001, pp. 32-42.
- Nonin Medical, Inc., "Operator's Manual—Models 8600F0 and 8600F0M Pulse Oximeters," 2005, 25 pages.
- C. J. Pujary, "Investigation of Photodetector Optimization in Reducing Power Consumption by a Noninvasive Pulse Oximeter Sensor," Worcester Polytechnic Institute, Jan. 16, 2004, 133 pages.
- B. McGarry et al., "Reflections on a candidate design of the user-interface for a wireless vital-signs monitor," Proceedings of DARE 2000 on Designing Augmented Reality Environments, Jan. 2000, pp. 33-40.
- J. C. D. Conway et al., "Wearable computer as a multi-parametric monitor for physiological signals," Proceedings IEEE International Symposium on Bio-Informatics and Biomedical Engineering, Arlington, VA, USA, 2000, pp. 236-242.
- J. A. Tamada et al., "Noninvasive Glucose Monitoring: Comprehensive Clinical Results," JAMA, Nov. 17, 1999, vol. 282, No. 19, pp. 1839-1844.
- B.-H. Yang et al., "Development of the ring sensor for healthcare automation," Robotics and Autonomous Systems, 2000, pp. 273-281
- Laukkanen RM et al., "Heart Rate Monitors: State of the Art," Journal of Sports Science, Jan. 1998, pp. S3-S7.
- S. Warren et al., "Designing Smart Health Care Technology into the Home of the Future," Workshops on Future Medical Devices: Home Care Technologies for the 21<sup>st</sup> Century, Apr. 1999, 19 pages.
- A. C. M. Dassel et al., "Reflectance Pulse Oximetry at the Forehead Improves by Pressure on the Probe," Journal of Clinical Monitoring, vol. 11, No. 4, Jul. 1995, pp. 237-244.
- B-H. Yang et al., "A Twenty-Four Hour Tele-Nursing System Using a Ringer Sensor," Proceedings of 1998 IEEE International Conference on Robotics and Automation, May 16-20, 1998, 6 pages.
- S. Rhee et al., "The Ring Sensor: a New Ambulatory Wearable Sensor for Twenty-Four Hour Patient Monitoring," Proceedings of the 20<sup>th</sup> Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Oct. 29-Nov. 1, 1998, 4 pages. S. Rhee et al., "Design of a Artifact-Free Wearable Plethysmographic Sensor," 21<sup>st</sup> Annual International Conference IEEE Engineering in
- Medicine and Biology Society, Oct. 13-16, 1999, p. 786.

  T. Martin et al., "Issues in Wearable Computing for Medical Montioring Applications: A Case Study of a Wearable ECG Monitoring Device," In Proceedings of International Symposium of Wearable Computers (ISWC'00), Feb. 2000, pp. 43-49.
- S. Rhee et al., "Artifact-Resistant, Power Efficient Design of Finger-Ring Plethysmographic Sensors, Part I: Design and Analysis," 22<sup>nd</sup> Annual International Conference IEEE Engineering in Medicine and Biology Society, Jul. 23-28, 2000, pp. 2792-2795.
- C. Pujary et al., "Photodetector Size Considerations in the Design of a Noninvasive Reflectance Pulse Oximeter for Telemedicine Applications," Proceedings of IEEE Annual Northeast Bioengineering Conference, 2003, pp. 148-149.
- M. Savage et al., "Optimizing Power Consumption in the Design of a Wearable Wireless Telesensor: Comparison of Pulse Oximeter

- Modes," Proceedings of IEEE 29<sup>th</sup> Annual Nonheust Bioengineering Conference, 2003, pp. 150-151.
- A. Tura et al., "A Wearable Device with Wireless Bluetooth-based Data Transmission," Measurement Science Review, vol. 3, Sec. 2, 2003, pp. 1-4.
- R. Paradiso, "Wearable Health Care System for Vital Signs Monitoring," In Proceedings of IEEE International Conference on Information Technology Applications in Biomedicine, May 2003, pp. 283-286.
- H.H. Asada et al., "Mobile Monitoring with Wearable Photoplethysmographic Biosensors," IEEE Engineering in Medicine and Biology Magazine, May/Jun. 2003, pp. 28-40.
- Y. Mendelson et al., "Minimization of LED Power Consumption in the Design of a Wearable Pulse Oximeter," Proceedings of the IASTED International Conference Biomedical Engineering, Jun. 25-27, 2003, 6 pages.
- Y. Mendelson et al., "Measurement Site and Photodetector Size Considerations in Optimizing Power Consumption of a Wearable Reflectance Pulse Oximeter," Proceedings of the 25<sup>th</sup> Annual International Conference of the IEEE EMBS, Sep. 17-21, 2003, pp. 3016-3019.
- D. Marculescu et al., "Ready to Ware," IEEE Spectrum, vol. 40, Issue 10, Oct. 2003, pp. 28-32.
- P. Celka et al., "Motion Resistant Earphone Located Infrared Based Hearth Rate Measurement Device," In Proceeding of the 2<sup>nd</sup> International Conference on Biomedical Engineering, Innsbruck, Austria, Feb. 16-18, 2004, pp. 582-585.
- D. Konstantas et al., "Mobile Patient Monitoring: The MobiHealth System," In Proceedings of International Conference on Medical and Care Compunetics, NCC'04, Feb. 2004, 8 pages.
- S. Pentland, "Healthwear: Medical Technology Becomes Wearable," IEEE Computer Society, vol. 37, Issue 5, May 2004, pp. 34-41.
- P. Branche et al., "Signal Quality and Power Consumption of a New Prototype Reflectance Pulse Oximeter Sensor," Proceeding of the 31th Annual Northeast Bioengineering Conference, Hoboken, NJ, IEEE, 2005, pp. 1-2.
- U. Anliker et al., "AMON: A Wearable Multiparameter Medical Monitoring and Alert System," IEEE Transactions on Information Technology in Biomedicine, Jan. 2005, pp. 1-11.
- P. T. Gibbs et al., "Active Motion Artifact Cancellation for Wearable Health Monitoring Sensors Using Collocated MEMS Accelerometers," Proceedings of SPIE Smart Structures and Materials: Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems, May 17, 2005, pp. 811-819.
- C. W. Mundt et al., "A Multiparameter Wearable Physiologic Monitoring System for Space and Terrestrial Applications," IEEE Transactions on Information Technology in Biomedicine, vol. 9, No. 3, Sep. 2005, pp. 382-391.
- Y. Mendelson et al., "A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 912-915
- B-S. Lin et al., "RTWPMS: A Real-Time Wireless Physiological Monitoring System," IEEE Transactions on Information Technology in Biomedicine, vol. 10, No. 4, Oct. 2006, pp. 647-656.
- T. Torfs et al., "Body-Heat Powered Autonomous Pulse Oximeter," IEEE Sensors 2006, EXCO, Oct. 22-25, 2006, pp. 427-430.
- P.S. Pandian et al., "Smart Vest: Wearable Multi-Parameter Remote Physiological Monitoring System," Medical Engineering & Physics 30, 2008. pp. 466-477.
- G. Tamannagari, "Power Efficient Design of Finder-Ring Sensor for Patient Monitoring," Master of Science in Electrical Engineering, The University of Texas at San Antonio, College of Engineering, Department of Electrical Engineering, Dec. 2008, 74 pages.
- M. Yamashita et al., "Development of a Ring-Type Vital Sign Telemeter," Biotelemetry XIII, Mar. 26-31, 1995, pp. 145-150. P. Renevey et al., "Wrist-Located Pulse Detection Using IR Signals,
- Activity and Nonlinear Artifact Cancellation," Proceedings of the 23<sup>rd</sup> Annual EMBS International Conference, Oct. 25-28, 2001, pp. 3030-3033.

### US 10,702,195 B1

Page 15

#### (56) References Cited

#### OTHER PUBLICATIONS

Y. Mendelson et al., "A Mobile PDA-Based Wireless Pulse Oximeter," Proceedings of the IASTED International Conference Telehealth, Jul. 19-21, 2005, pp. 1-6.

P. Shaltis et al., "Novel Design for a Wearable, Rapidly Depolyable, Wireless Noninvasive Triage Sensor," Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27th Annual Conference, Sep. 1-4, 2005, pp. 3567-3570.

- Y-S. Yan et al., An Efficient Motion-Resistant Method for Wearable Pulse Oximeter, IEEE Transactions on Information Technology in Biomedicine, vol. 12, No. 3, May 2008, pp. 399-405.
- P. C. Branche et al., "Measurement Reproducibility and Sensor Placement Considerations in Designing a Wearable Pulse Oximeter for Military Applications," IEEE, 2004, pp. 216-217.
- G. Comtois, "A Comparative Evaluation of Adaptive Noise Cancellation Algorithms for Minimizing Motion Artifacts in a Forehead-Mounted Wearable Pulse Oximeter," Proceedings of the 29<sup>th</sup> Annual international Conference of the IEEE EMBS, Aug. 23-26, 2007, pp. 1528-1531
- G. Comtois et al., "A Noise Reference Input to an Adaptive Filter Algorithm for Signal Processing in a Wearable Pulse Oximeter," IEEE, 2007, pp. 106-107.

- R. P. Dresher et al., "A New Reflectance Pulse Oximeter Housing to Reduce Contact Pressure Effects," IEEE, 2006, pp. 49-50.
- R. P. Dresher et al., "Reflectance Forehead Pulse Oximetry: Effects on Contact Pressure During Walking," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 3529-3532.
- W. S. Johnston et al., "Extracting Breathing Rate Information from a Wearable Reflectance Pulse Oximeter Sensor," Proceedings of the 26<sup>th</sup> Annual International Conference of the IEEE EMBS, Sep. 1-5, 2004, pp. 5388-5391.
- W. Johnston et al., "Extracting Heart Rate Variability from a Wearable Reflectance Pulse Oximeter," IEEE, 2005, pp. 1-2.
- W. S. Johnston et al., "Investigation of Signal Processing Algorithms for an Embedded Microcontroller-Based Wearable Pulse Oximeter," Proceedings of the 28<sup>th</sup> IEEE EMBS Annual International Conference, Aug. 30-Sep. 3, 2006, pp. 5888-5891.
- P. Lukowicz et al., "AMON: A Wearable Medical Computer for High Risk Patient," Proceedings of the 6<sup>th</sup> International Symposium on Wearable Computers (ISWC'02), 2002, pp. 1-2.
- P. Lukowicz et al., "The WearARM Modular, Low-Power Computing Core," IEEE Micro, May-Jun. 2001, pp. 16-28.
- Y. Mendelson et al., "Accelerometery-Based Adaptive Noise Cancellation for Remote Physiological Monitoring by a Wearable Pulse Oximeter," Proceedings of the 3<sup>rd</sup> IASTED International Conference TELEHEALTH, May 31-Jun. 1, 2007, pp. 28-33.

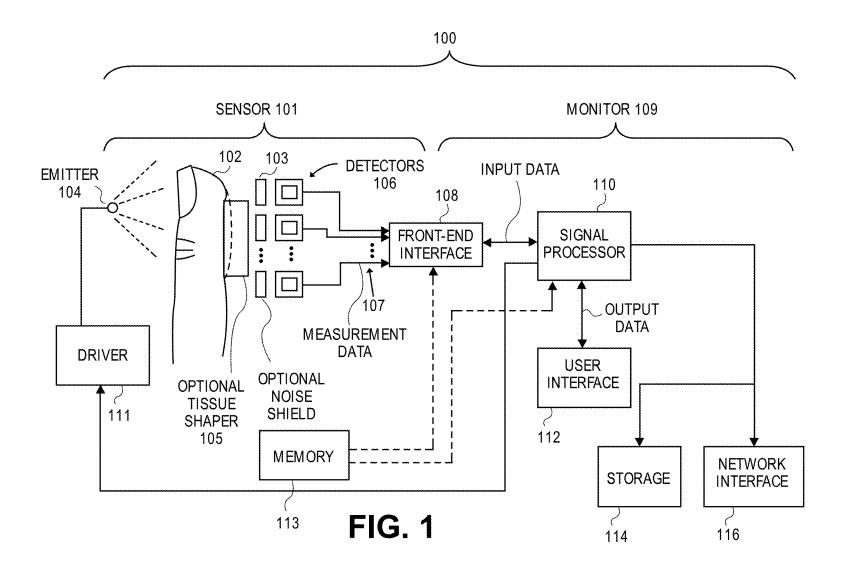
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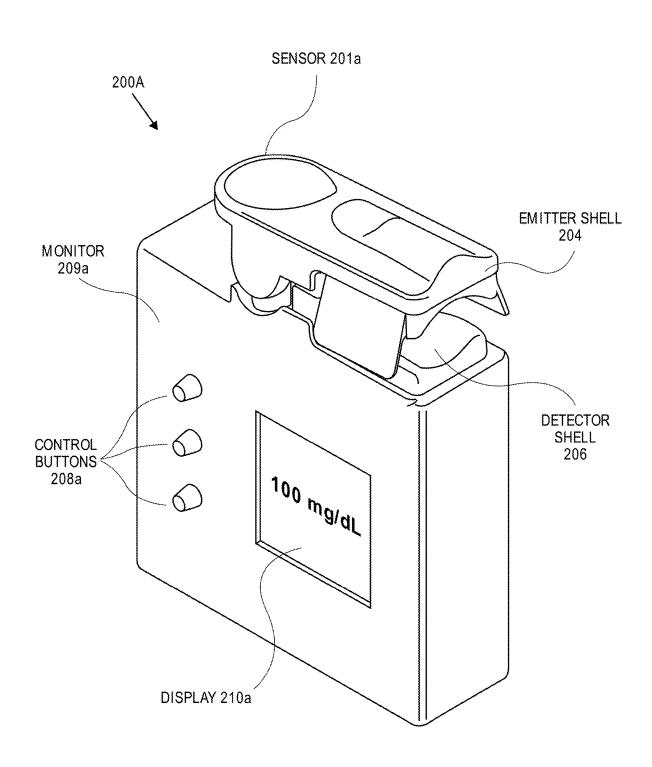


FIG. 2A

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Appx00534

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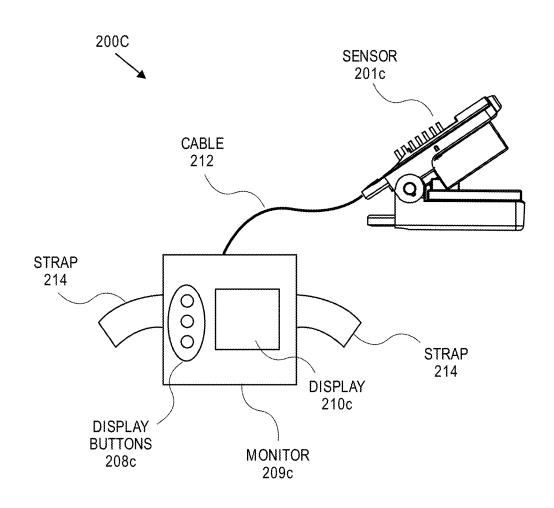


FIG. 2C

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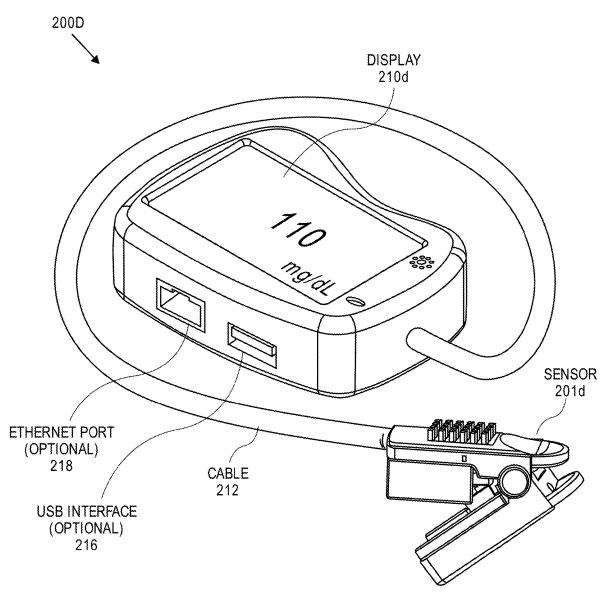
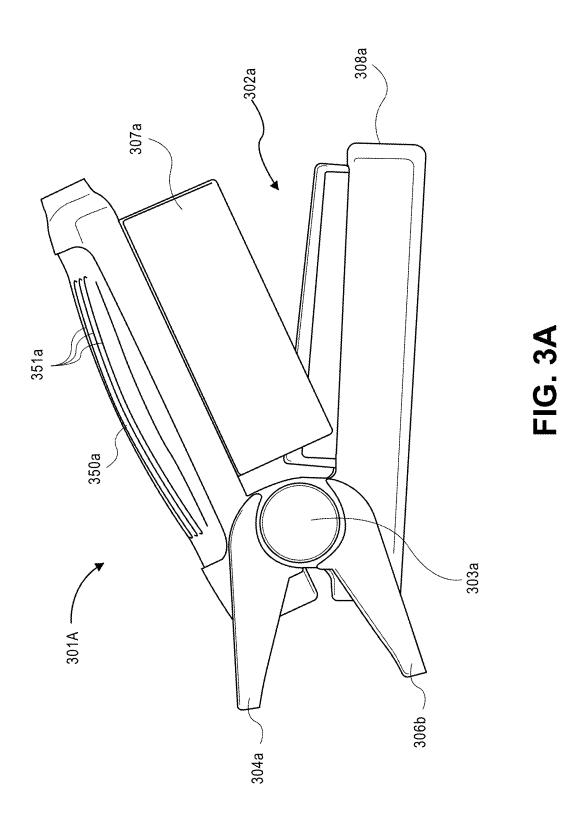


FIG. 2D

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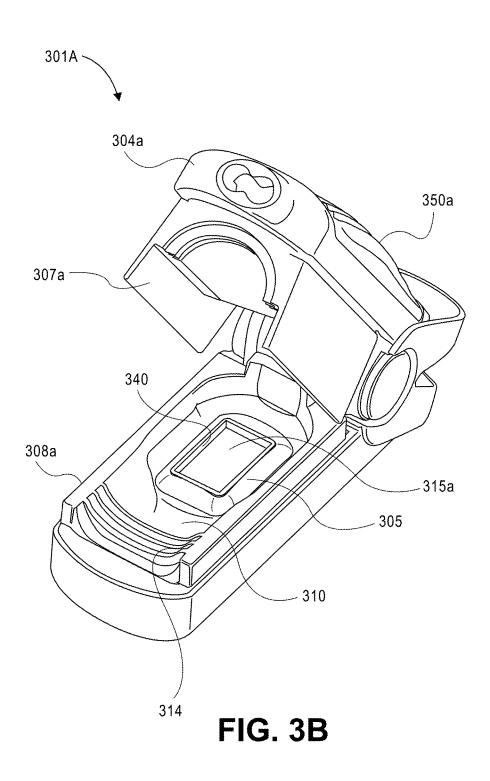


**Appx00537** 

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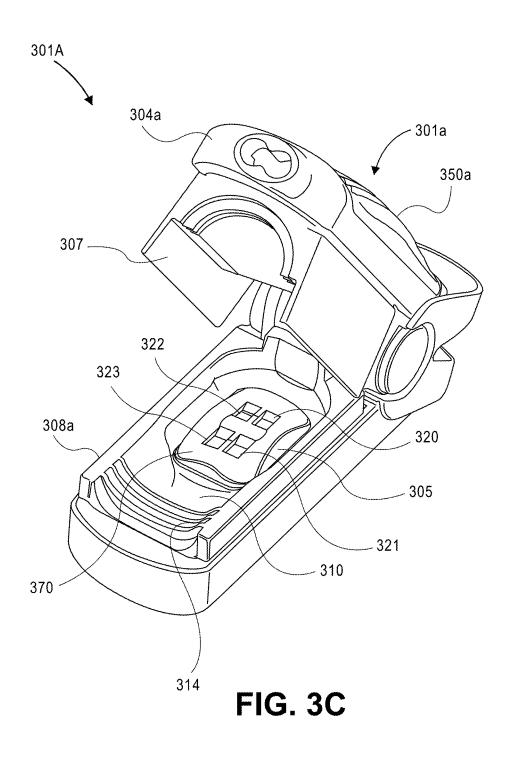


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**Appx00539** 

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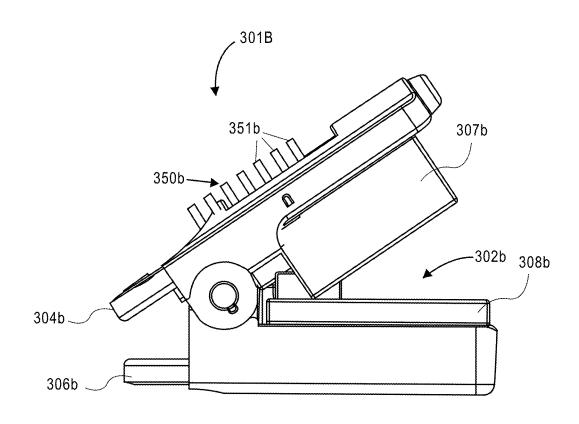


FIG. 3D

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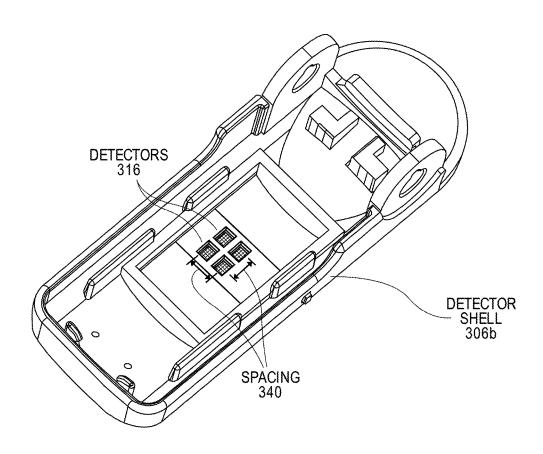
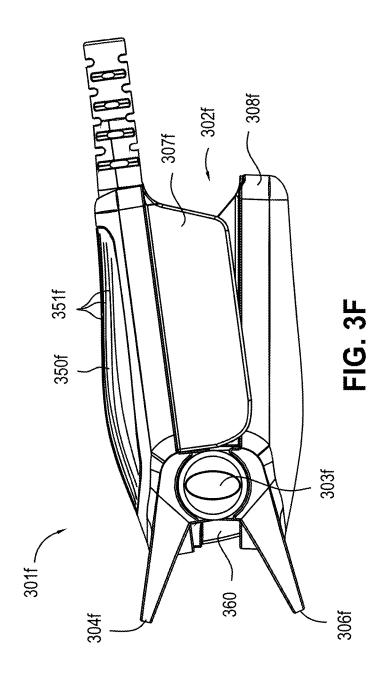


FIG. 3E

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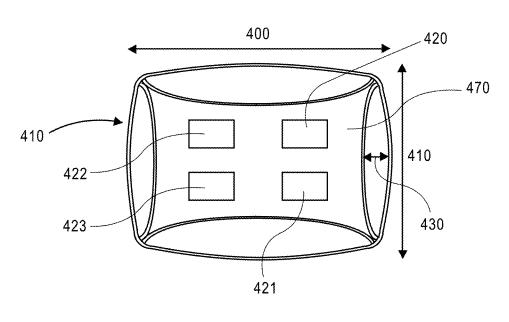


FIG. 4A

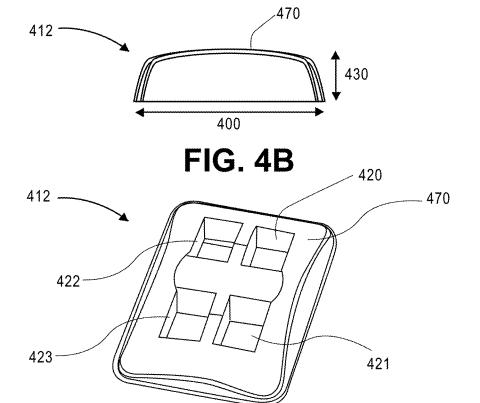
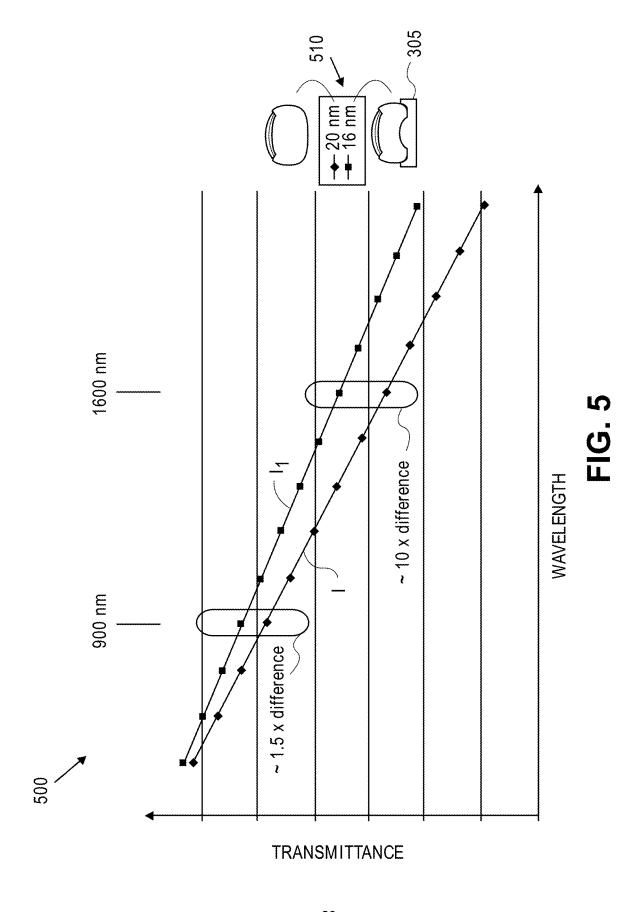


FIG. 4C

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Appx00544

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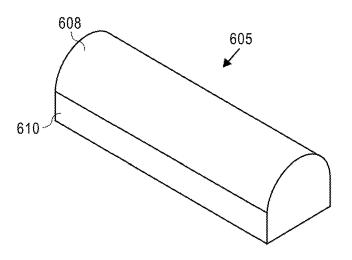


FIG. 6A

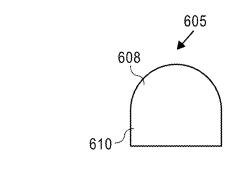


FIG. 6B

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a

FIG. 6C

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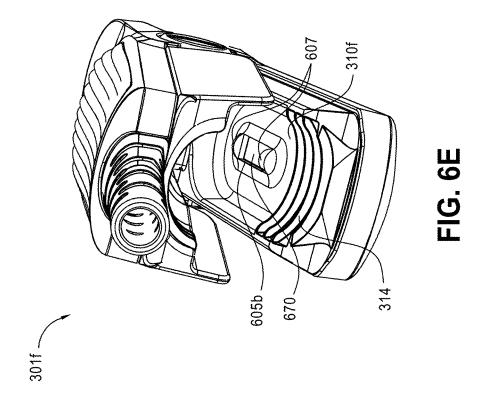
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FIG. 6D

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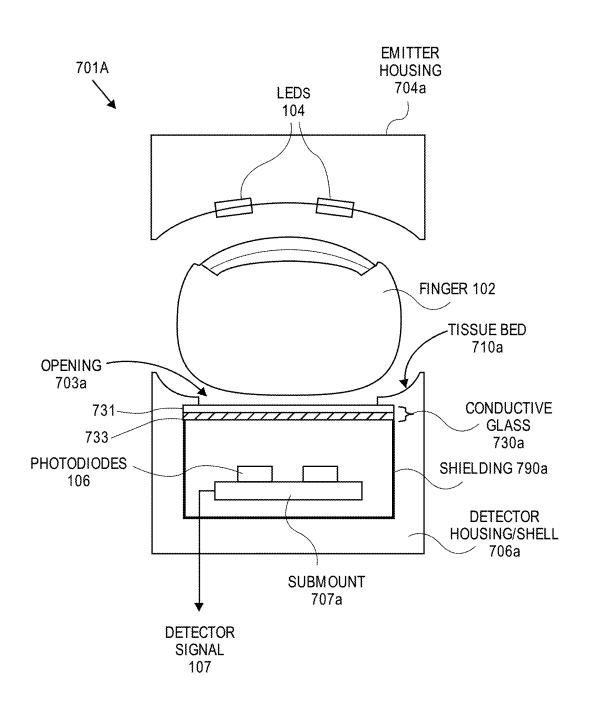


FIG. 7A

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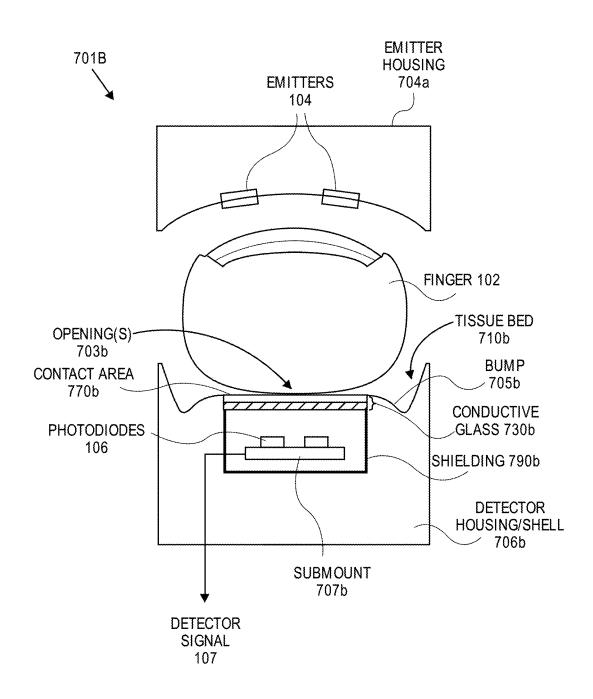
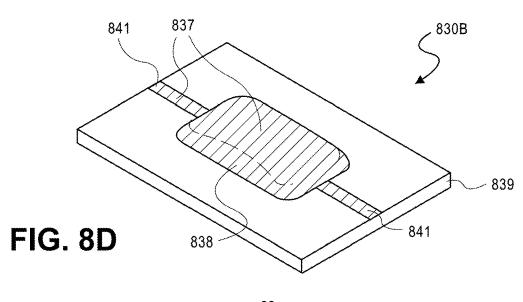


FIG. 7B

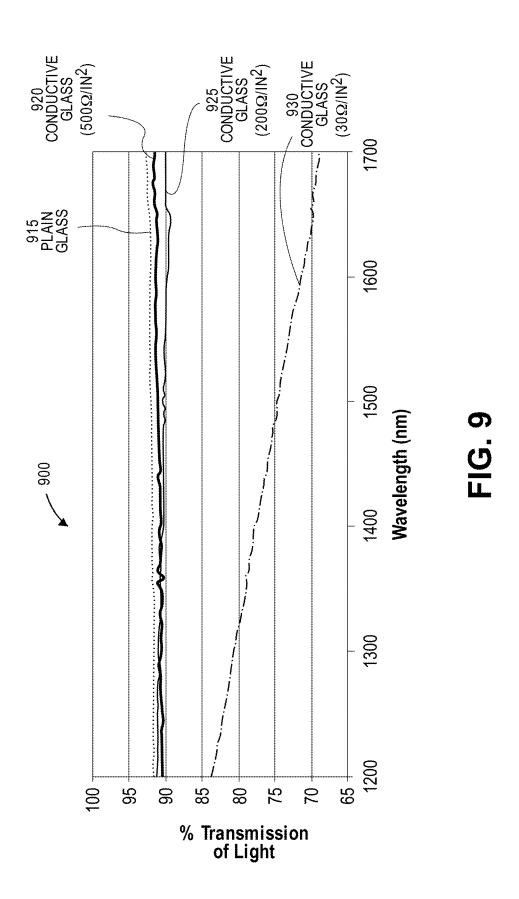
U.S. Patent US 10,702,195 B1 Jul. 7, 2020 **Sheet 18 of 65** 730 731 733 820 FIG. 8A -731 FIG. 8B 830A **731** 733 -835

FIG. 8C

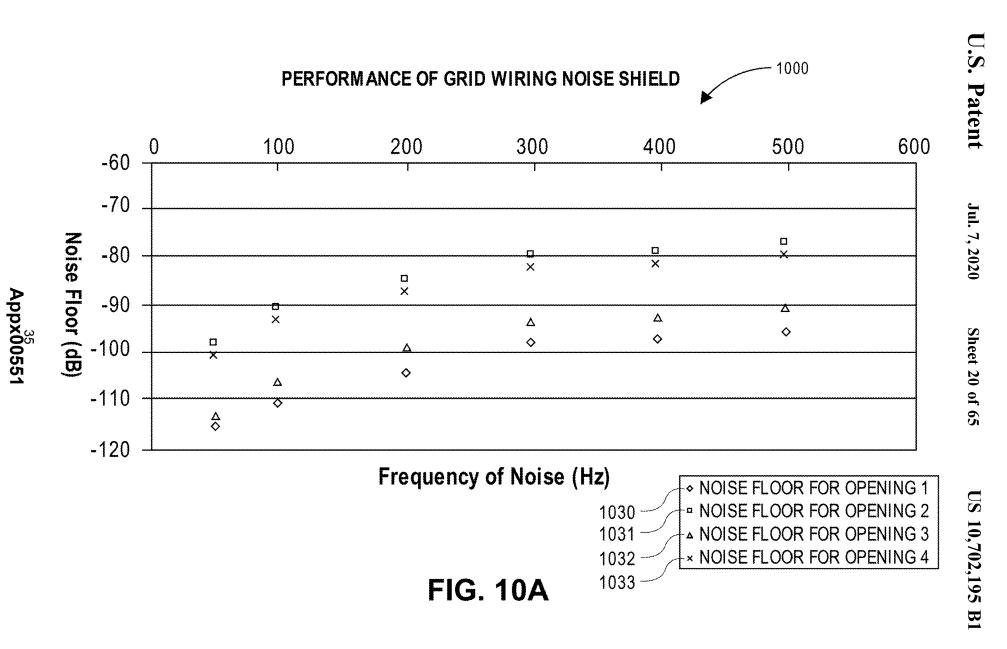


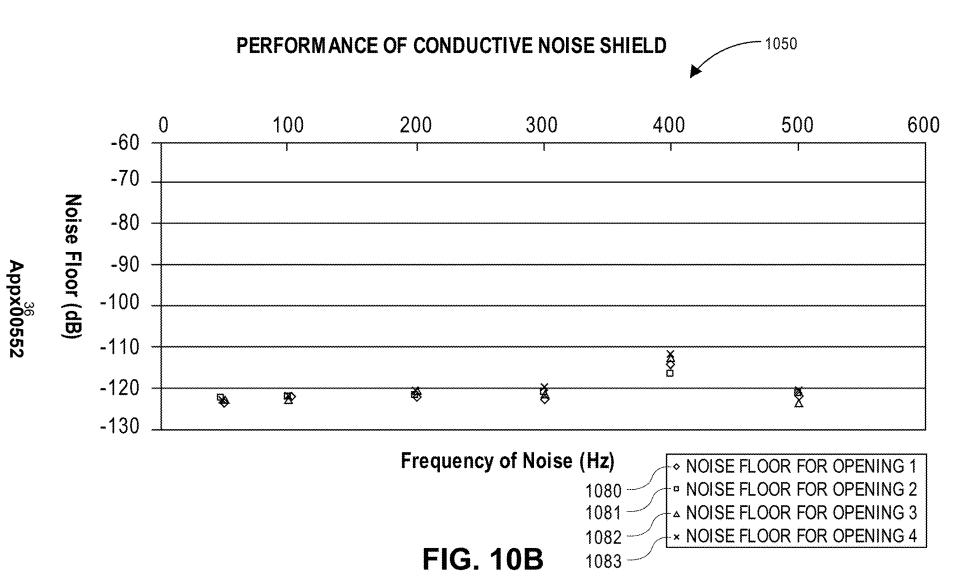
Appx00549

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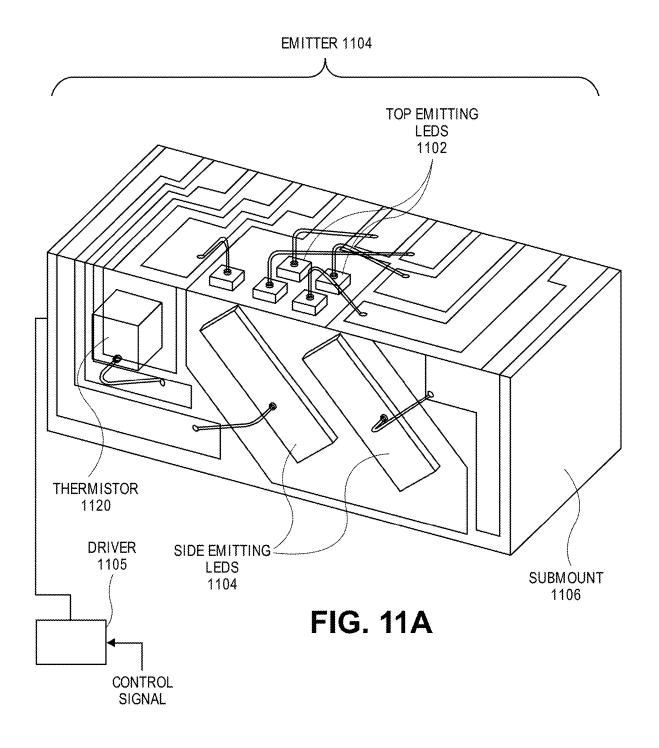


**Appx00550** 

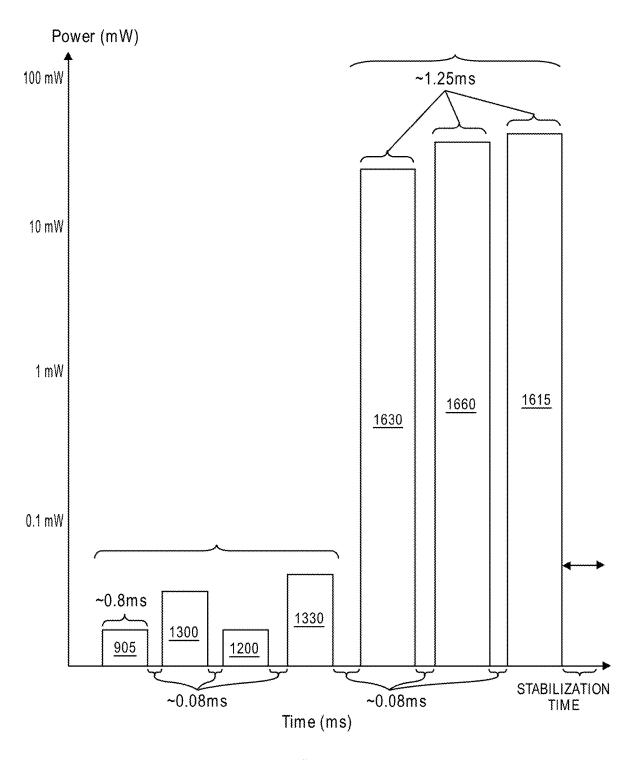




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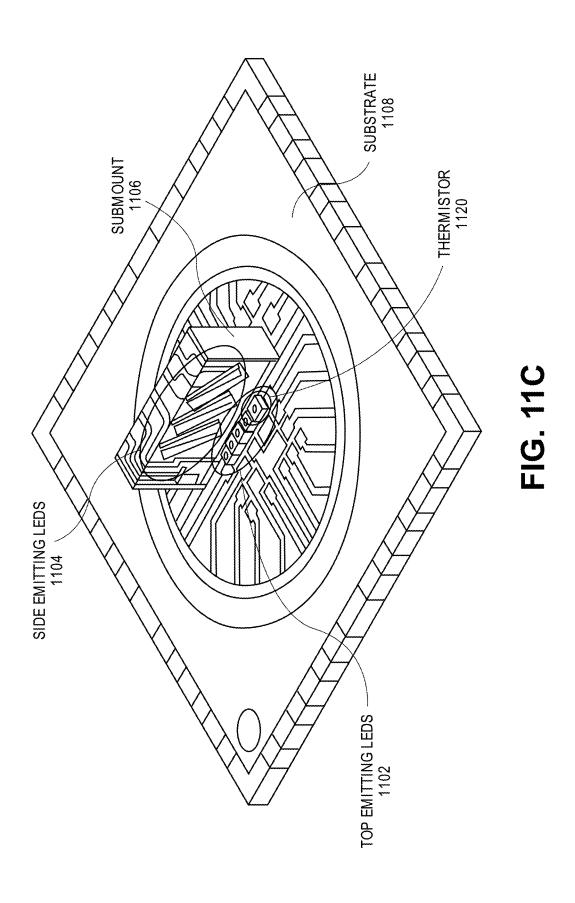


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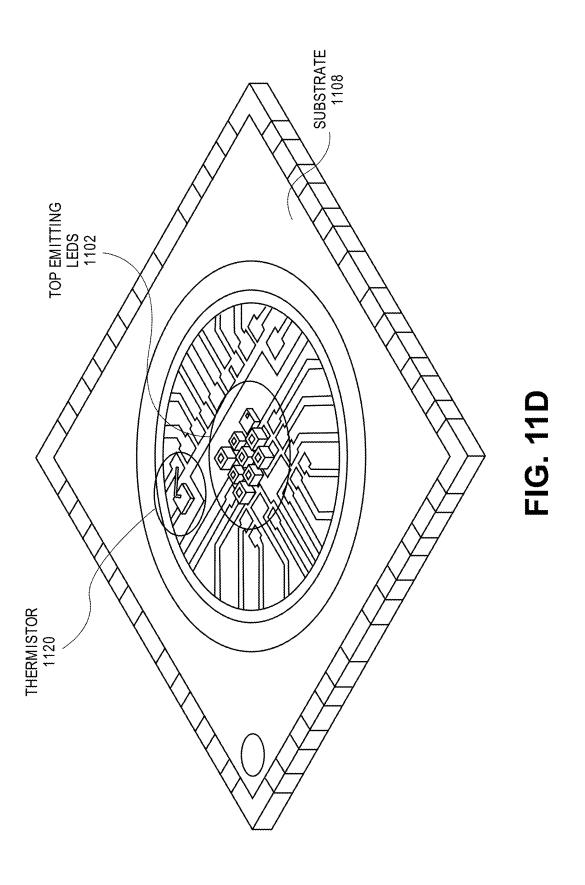
**FIG. 11B** 

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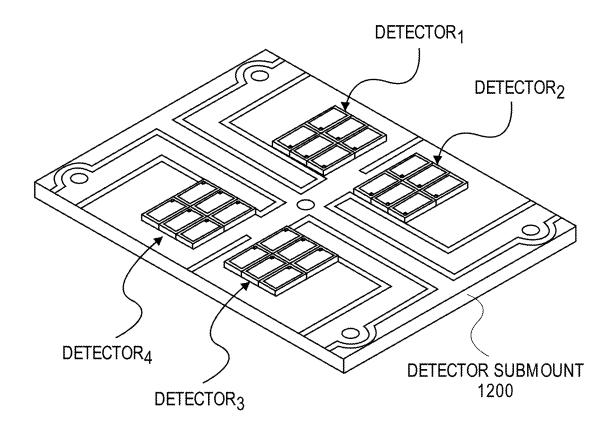


**Appx00555** 

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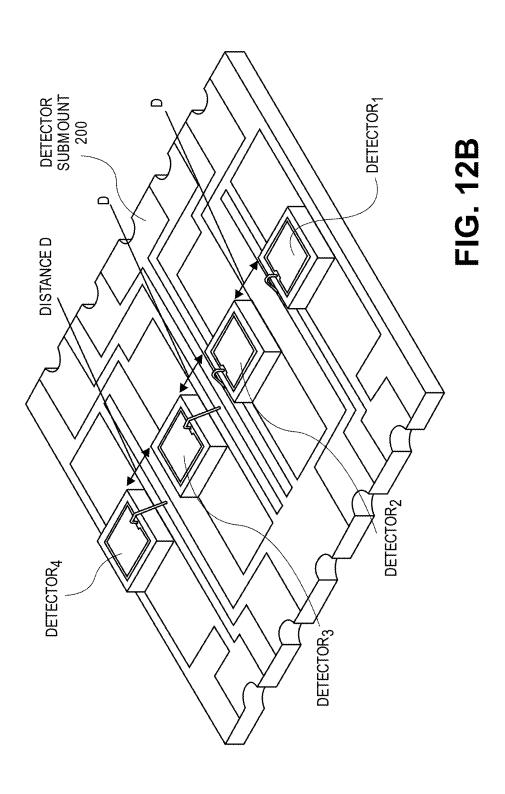


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**FIG. 12A** 

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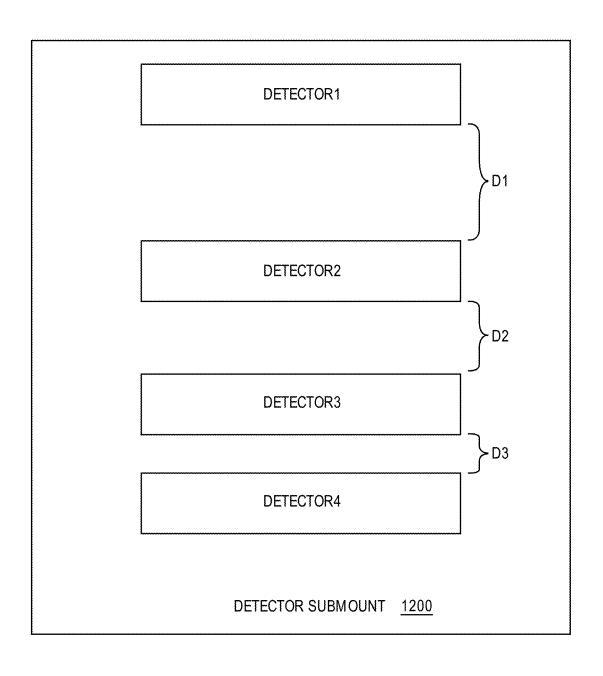
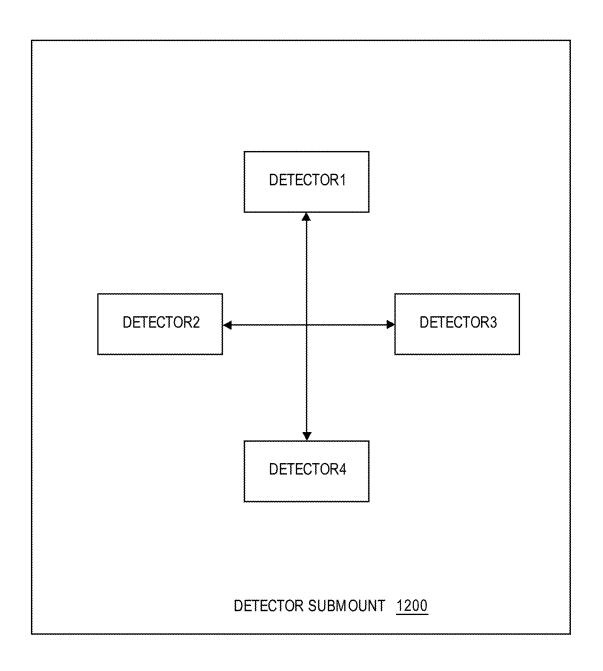


FIG. 12C

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**FIG. 12D** 

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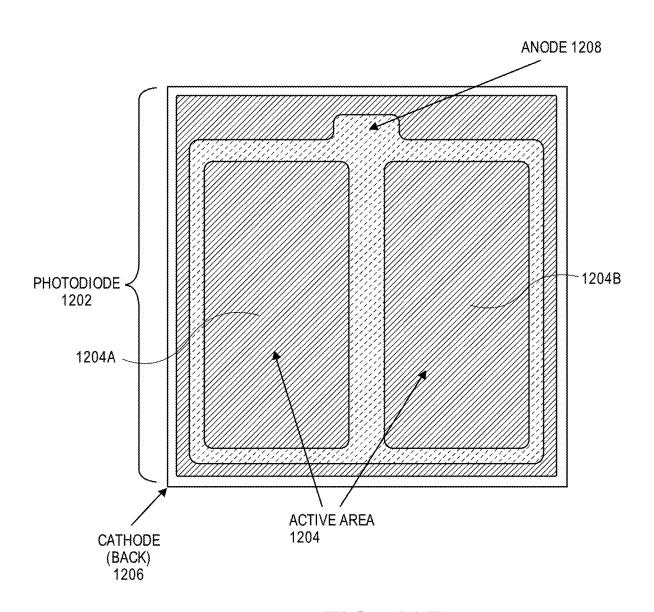


FIG. 12E

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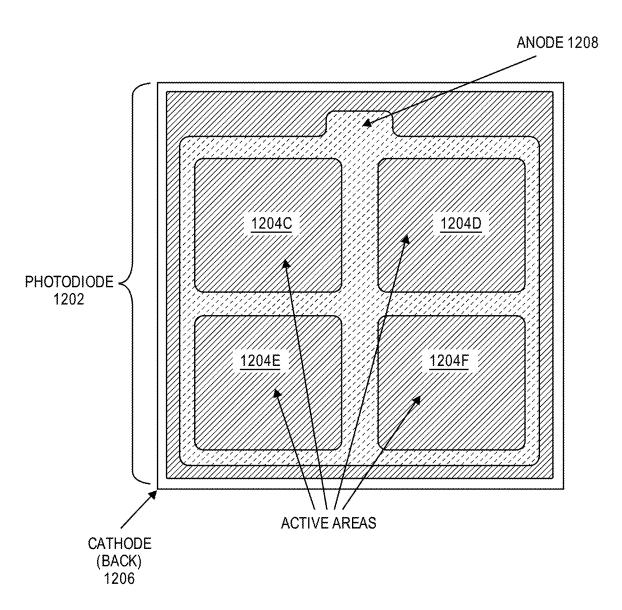


FIG. 12F

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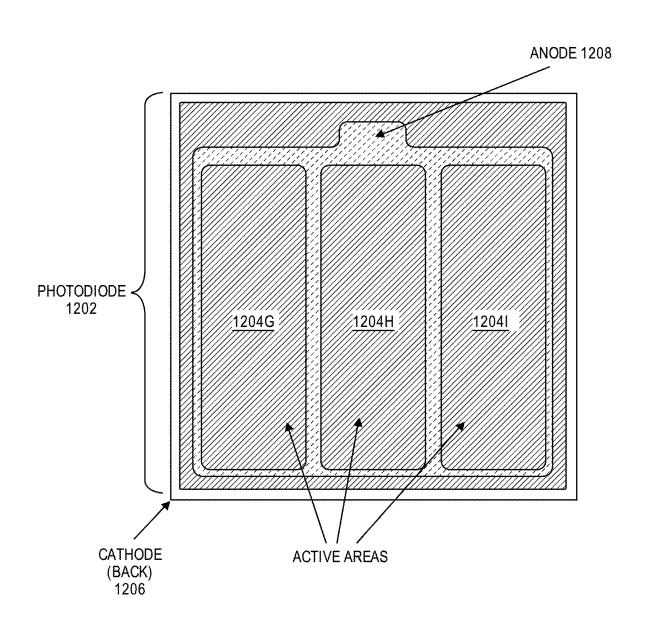


FIG. 12G

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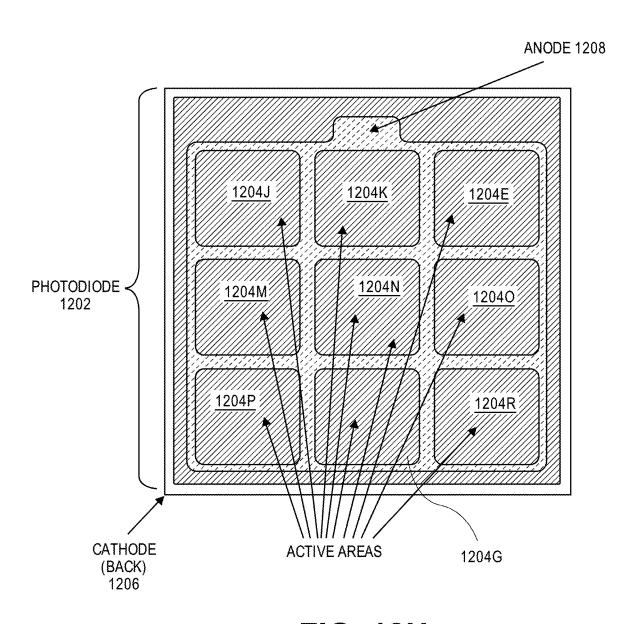
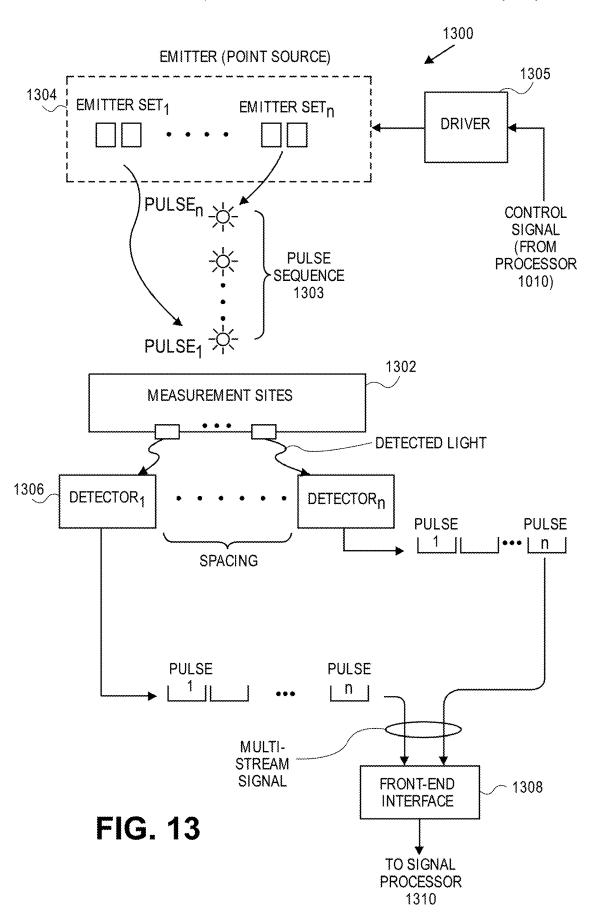


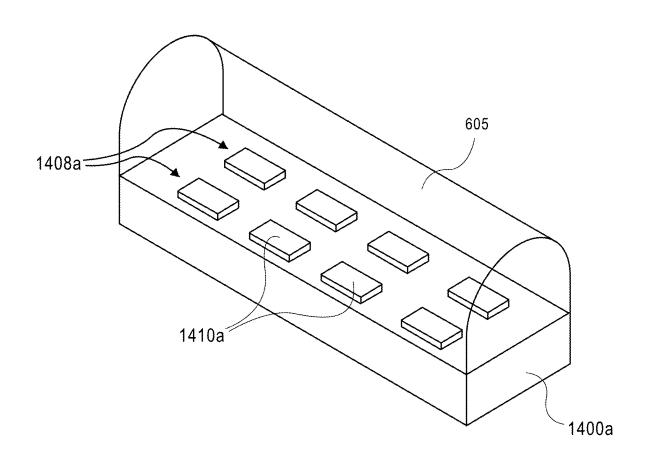
FIG. 12H

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**Appx00565** 

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**FIG. 14A** 

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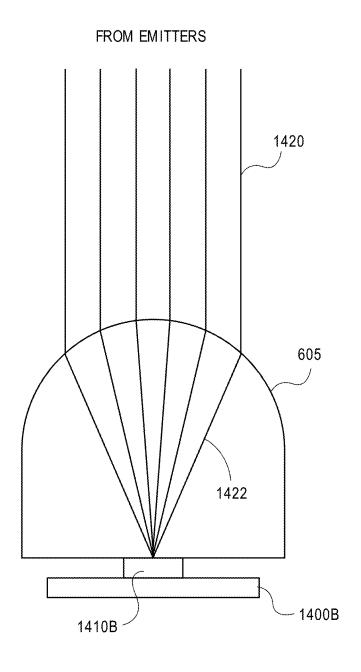


FIG. 14B

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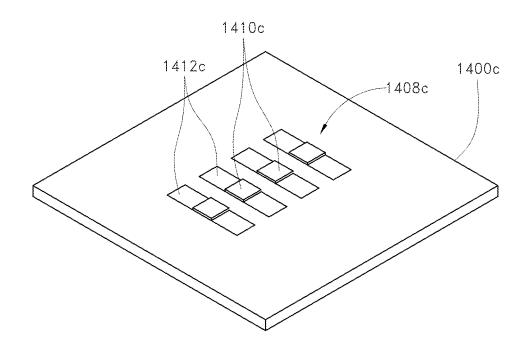


FIG. 14C

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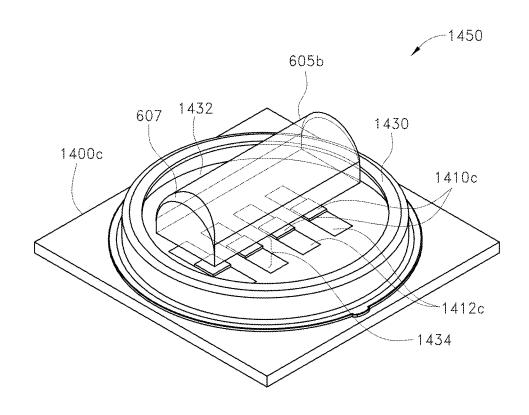


FIG. 14D

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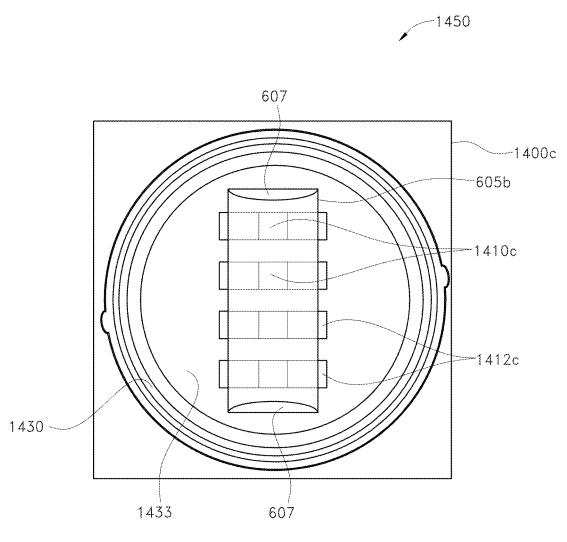


FIG. 14E

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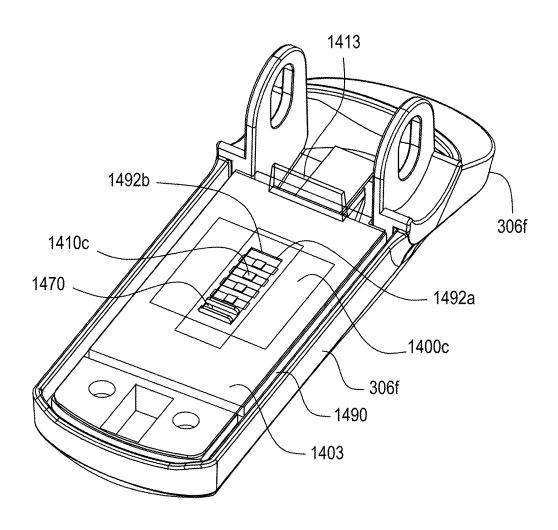


FIG. 14F

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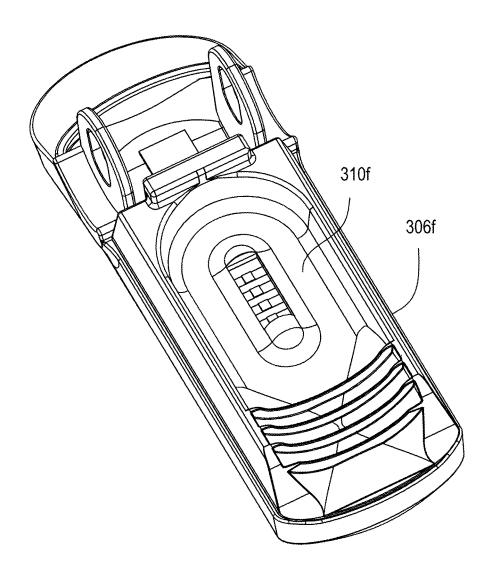


FIG. 14G

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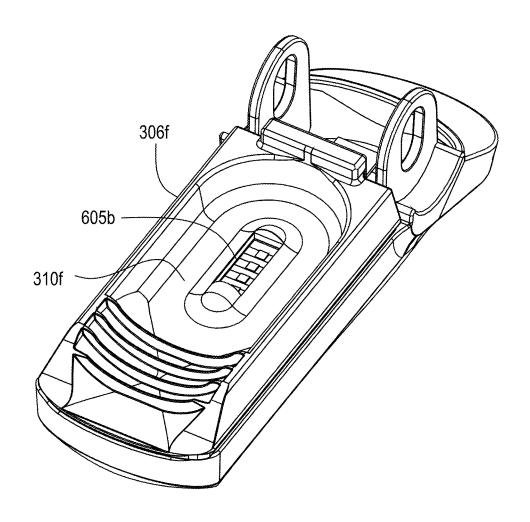


FIG. 14H

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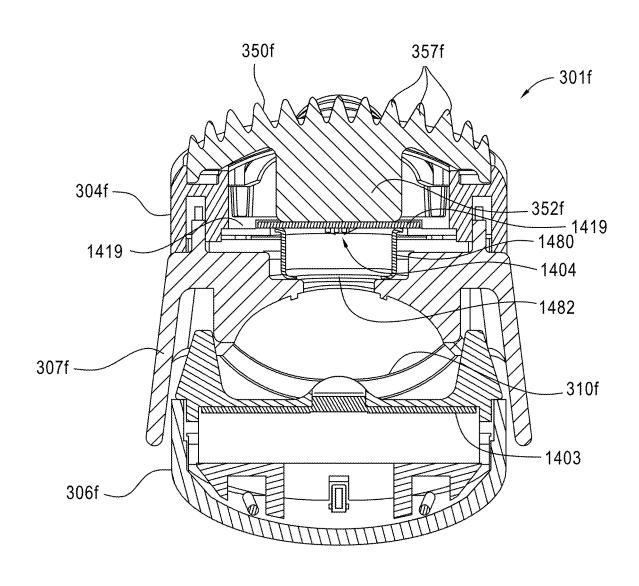
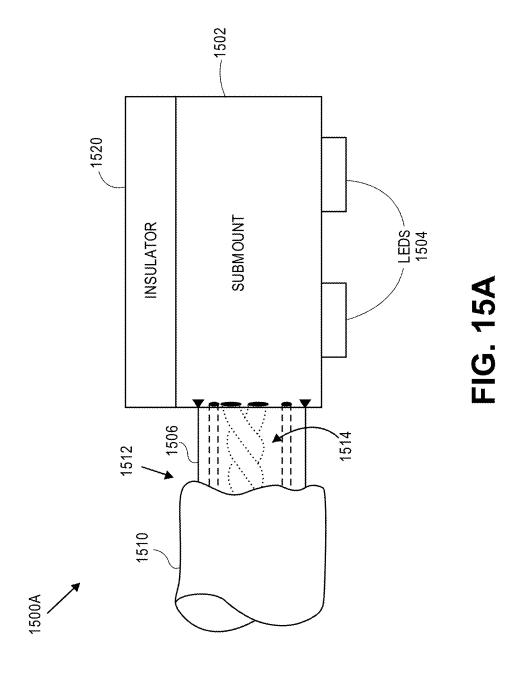


FIG. 141

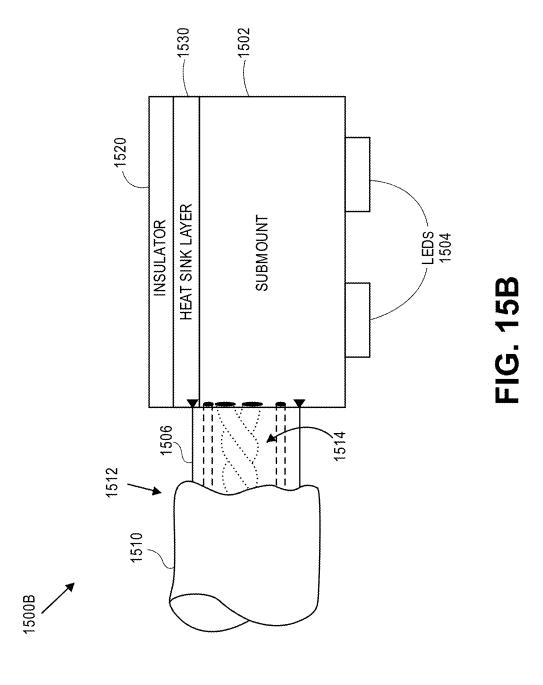
U.S. Patent Jul

Jul. 7, 2020

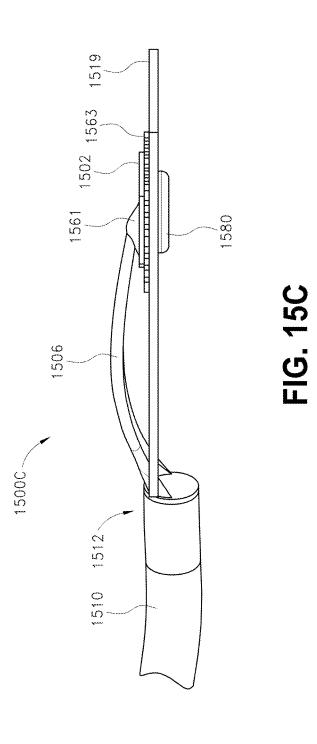
**Sheet 44 of 65** 



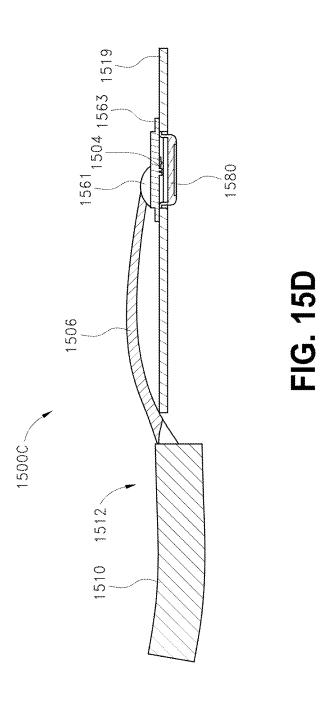
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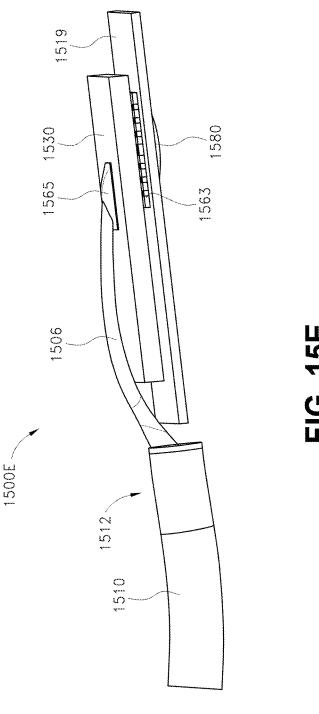
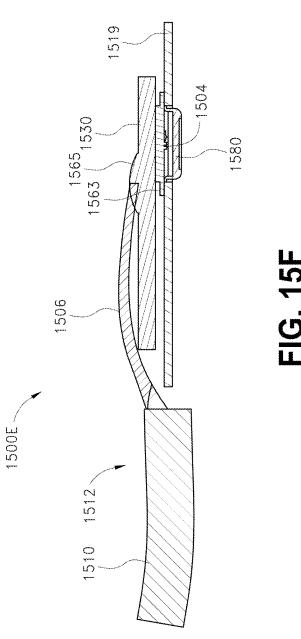


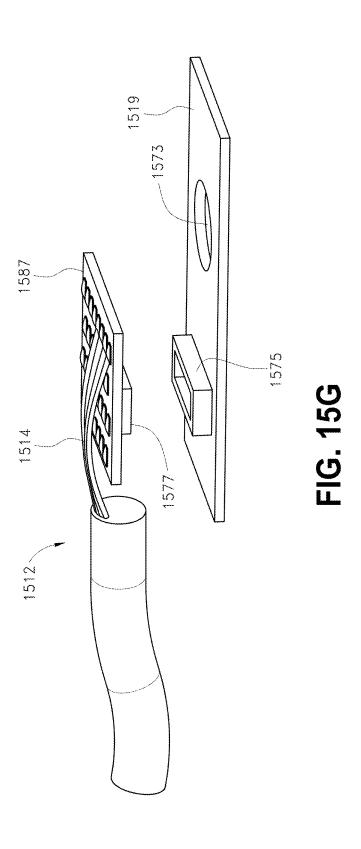
FIG. 15E

Case: 22-1972 Document: 33-2 Page: 278 Filed: 05/11/2023

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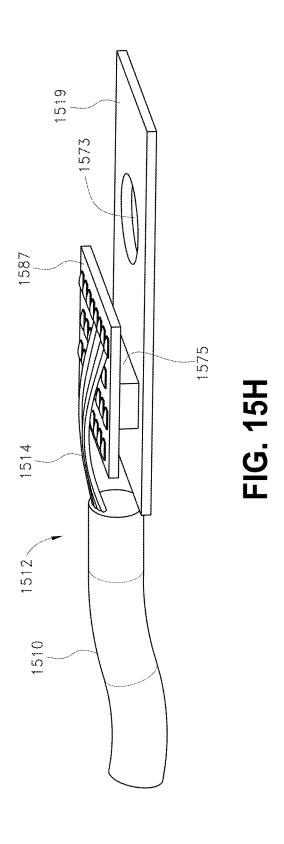
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FIG. 151

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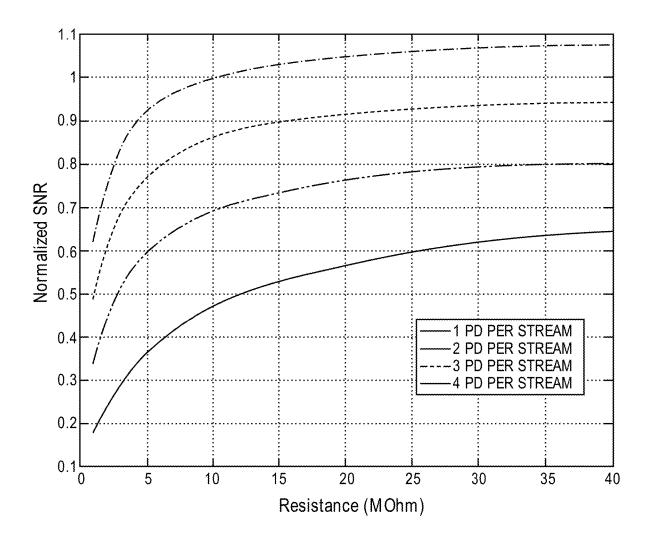


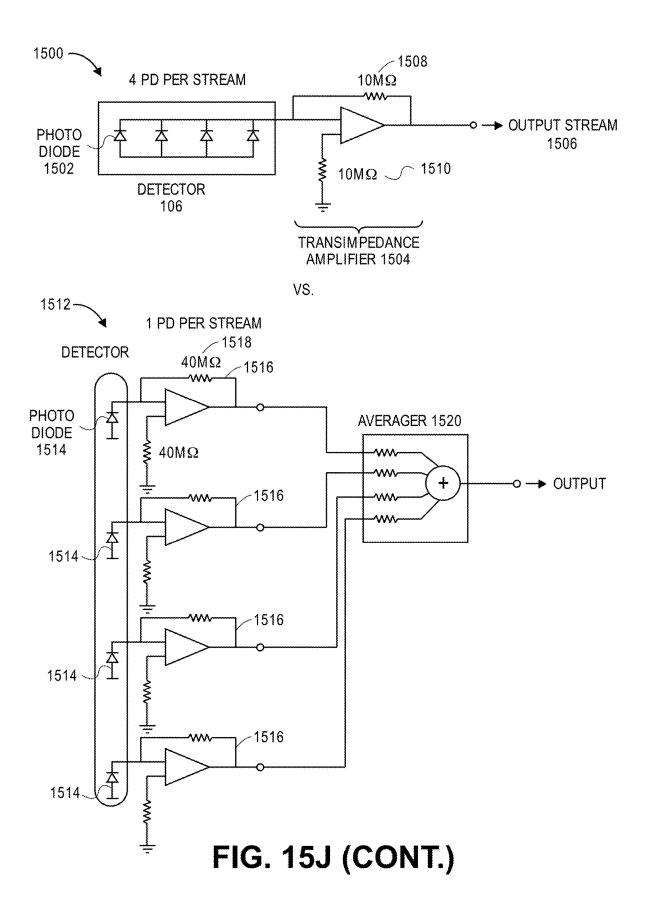
FIG. 15J

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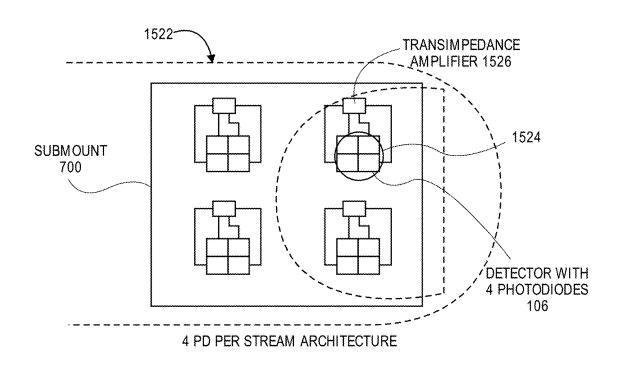
US 10,702,195 B1

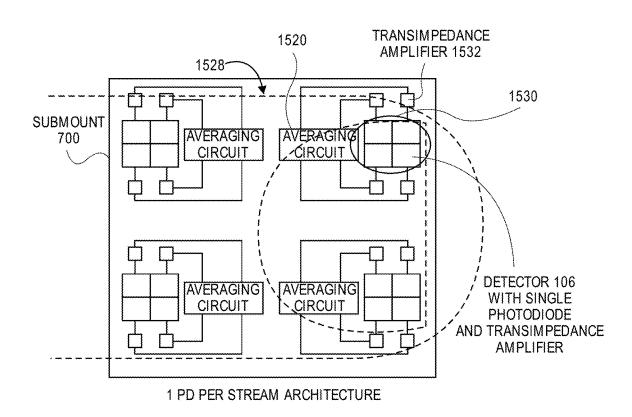


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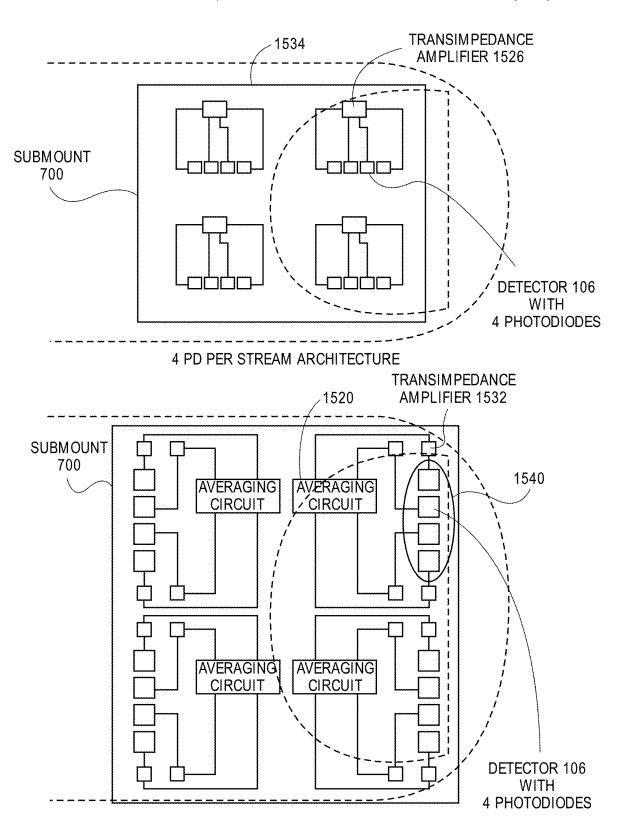
**Sheet 55 of 65** 





**FIG. 15K** 

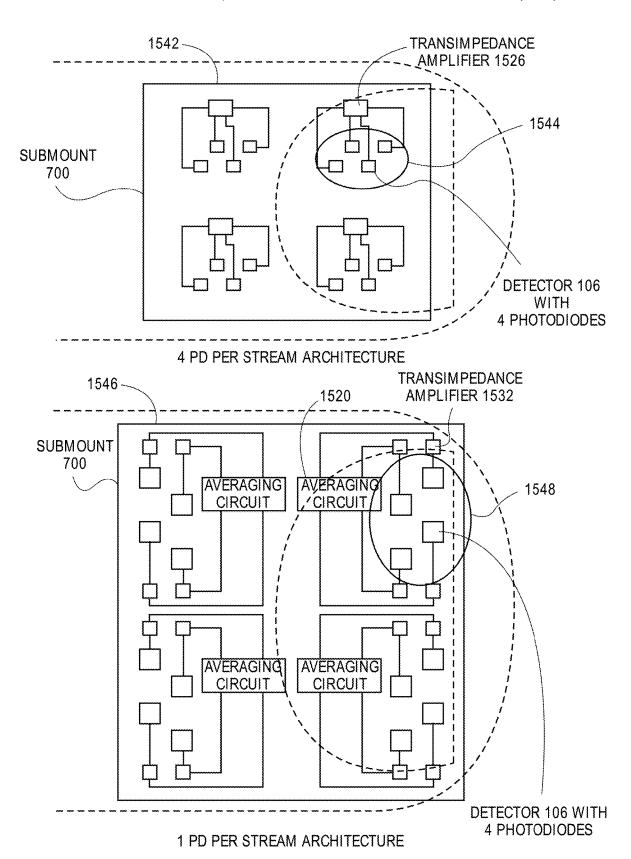
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1 PD PER STREAM ARCHITECTURE

FIG. 15K (CONT.)

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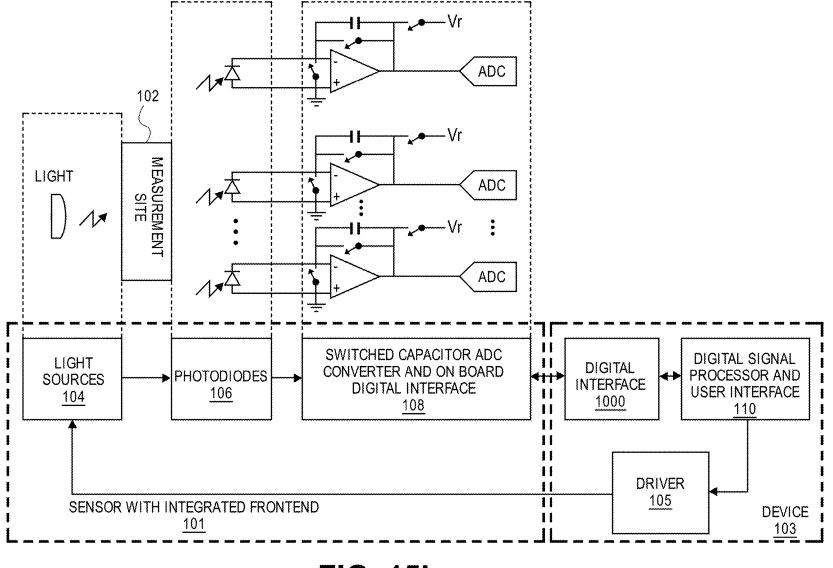
**FIG. 15K (CONT.)** 

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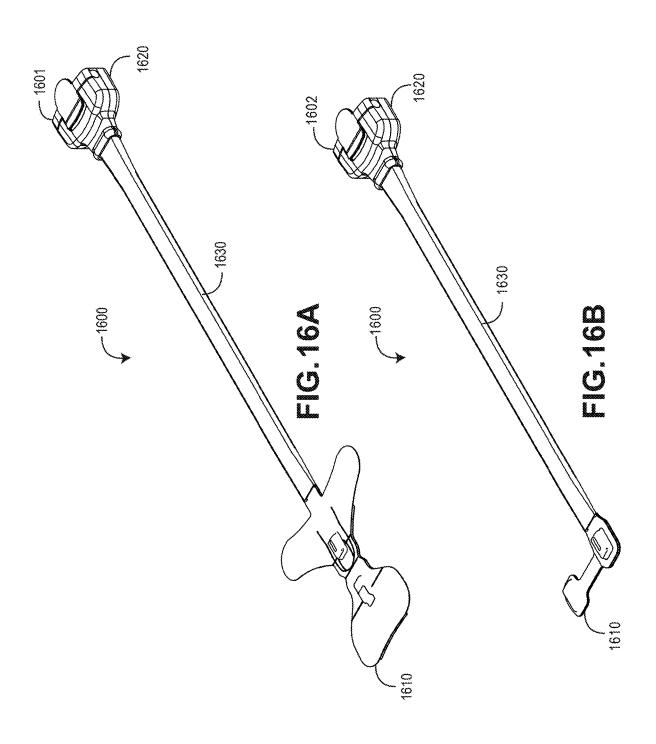
Appx00589

FIG. 15L

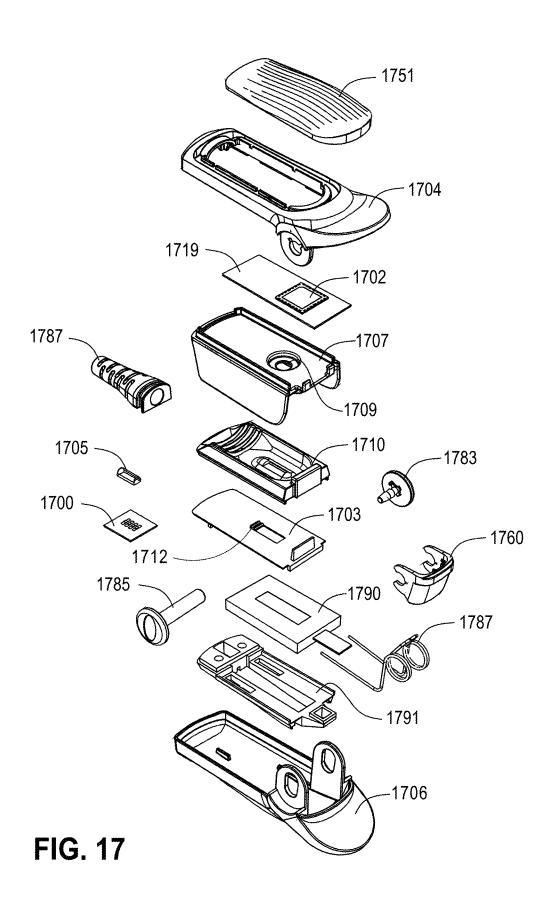
Filed: 05/11/2023

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Appx00591

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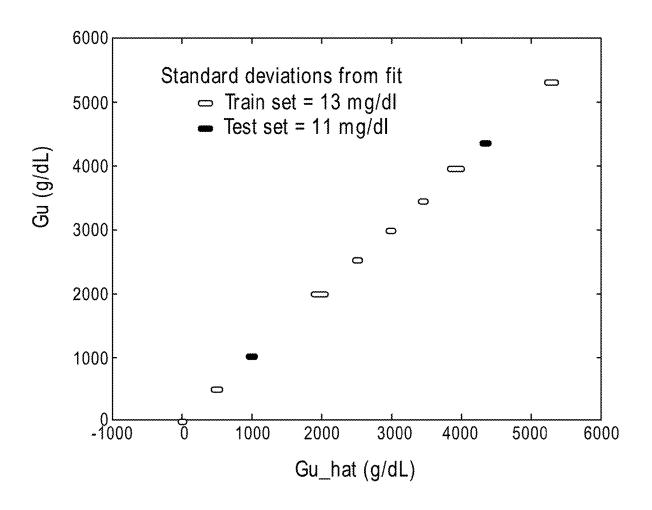


FIG. 18

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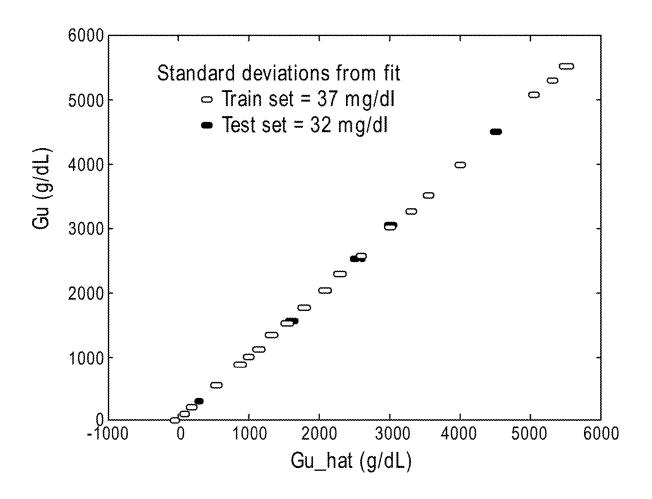


FIG. 19

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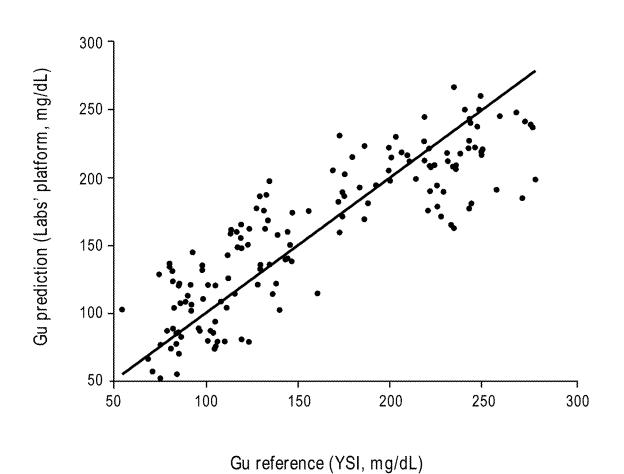


FIG. 20

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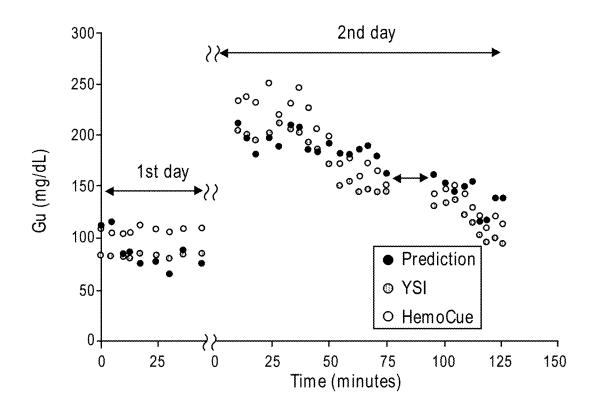


FIG. 21

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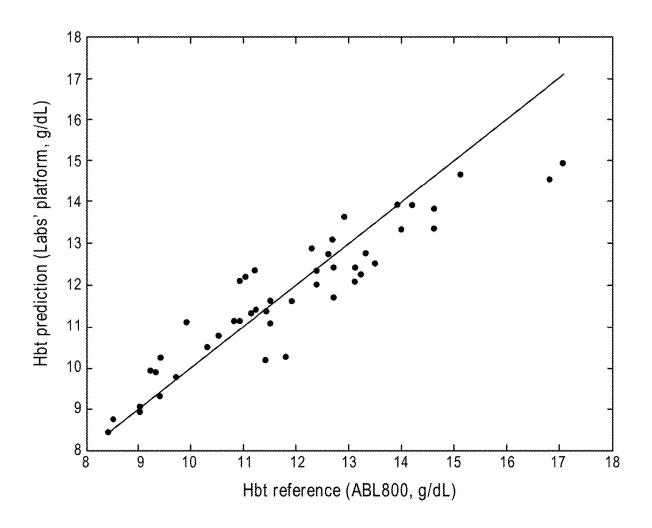


FIG. 22

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#### 1

#### MULTI-STREAM DATA COLLECTION SYSTEM FOR NONINVASIVE MEASUREMENT OF BLOOD CONSTITUENTS

#### RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/725,292, filed Dec. 23, 2019, which is a continuation of U.S. patent application Ser. No. 16/534,949, filed Aug. 7, 2019, which is a continuation of U.S. patent application Ser. No. 16/409,515, filed May 10, 2019, which is a continuation of U.S. patent application Ser. No. 16/261, 326, filed Jan. 29, 2019, which is a continuation of U.S. patent application Ser. No. 16/212,537, filed Dec. 6, 2018, 15 which is a continuation of U.S. patent application Ser. No. 14/981,290 filed Dec. 28, 2015, which is a continuation of U.S. patent application Ser. No. 12/829,352 filed Jul. 1, 2010, which is a continuation of U.S. patent application Ser. No. 12/534,827 filed Aug. 3, 2009, which claims the benefit 20 of priority under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/829,352 25 is also a continuation-in-part of U.S. patent application Ser. No. 12/497,528 filed Jul. 2, 2009, which claims the benefit of priority under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 30 4, 2008, 61/086,057 filed Aug. 4, 2008, 61/078,228 filed Jul. 3, 2008, 61/078,207 filed Jul. 3, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/497,528 also claims the benefit of priority under 35 U.S.C. § 120 as a continuation-in-part of the following U.S. Design patent 35 application Ser. No. 29/323,409 filed Aug. 25, 2008 and Ser. No. 29/323,408 filed Aug. 25, 2008. U.S. patent application Ser. No. 12/829,352 is also a continuation-in-part of U.S. patent application Ser. No. 12/497,523 filed Jul. 2, 2009, which claims the benefit of priority under 35 U.S.C. § 119(e) 40 of the following U.S. Provisional Patent Application Nos. 61/086,060 filed Aug. 4, 2008, 61/086,108 filed Aug. 4, 2008, 61/086,063 filed Aug. 4, 2008, 61/086,057 filed Aug. 4, 2008, 61/078,228 filed Jul. 3, 2008, 61/078,207 filed Jul. 3, 2008, and 61/091,732 filed Aug. 25, 2008. U.S. patent 45 application Ser. No. 12/497,523 also claims the benefit of priority under 35 U.S.C. § 120 as a continuation-in-part of the following U.S. Design patent application Ser. No. 29/323,409 filed Aug. 25, 2008 and Ser. No. 29/323,408 filed Aug. 25, 2008.

This application is related to the following U.S. Patent Applications:

application Filing Ser. No. Date	Title	Attonery Docket
12/497,528 Jul. 2, 2009	Noise Shielding for Noninvasive Device	MASCER.006A
12/497,523 Jul. 2, 2009	Contoured Protrusion for Improving Spectroscopic Measurement of Blood Constituents	MASCER.007A
12/497,506 Jul. 2, 2009	Heat Sink for Noninvasive Medical Sensor	MASCER.011A
12/534,812 Aug. 3, 2009	Multi-Stream Sensor Front Ends for Non-Invasive Measurement of Blood Constituents	MASCER.003A

## 2 -continued

application Filing Ser. No. Date	Title	Attonery Docket
12/534,823 Aug. 3, 2009	Multi-Stream Sensor for Non-Invasive Measurement of Blood Constituents	MASCER.004A
12/534,825 Aug. 3, 2009	Multi-Stream Emitter for Non-Invasive Measurement of Blood Constituents	MASCER.005A

The foregoing applications are hereby incorporated by reference in their entirety.

#### **BACKGROUND**

The standard of care in caregiver environments includes patient monitoring through spectroscopic analysis using, for example, a pulse oximeter. Devices capable of spectroscopic analysis generally include a light source(s) transmitting optical radiation into or reflecting off a measurement site, such as, body tissue carrying pulsing blood. After attenuation by tissue and fluids of the measurement site, a photodetection device(s) detects the attenuated light and outputs a detector signal(s) responsive to the detected attenuated light. A signal processing device(s) process the detector(s) signal(s) and outputs a measurement indicative of a blood constituent of interest, such as glucose, oxygen, met hemoglobin, total hemoglobin, other physiological parameters, or other data or combinations of data useful in determining a state or trend of wellness of a patient.

In noninvasive devices and methods, a sensor is often adapted to position a finger proximate the light source and light detector. For example, noninvasive sensors often include a clothespin-shaped housing that includes a contoured bed conforming generally to the shape of a finger.

#### SUMMARY

This disclosure describes embodiments of noninvasive methods, devices, and systems for measuring a blood constituent or analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. These characteristics can relate, for example, to pulse rate, hydration, trending information and analysis, and the like.

In an embodiment, the system includes a noninvasive sensor and a patient monitor communicating with the non-invasive sensor. The non-invasive sensor may include different architectures to implement some or all of the disclosed features. In addition, an artisan will recognize that the non-invasive sensor may include or may be coupled to other components, such as a network interface, and the like. Moreover, the patient monitor may include a display device, a network interface communicating with any one or combination of a computer network, a handheld computing device, a mobile phone, the Internet, or the like. In addition, embodiments may include multiple optical sources that emit light at a plurality of wavelengths and that are arranged from the perspective of the light detector(s) as a point source.

In an embodiment, a noninvasive device is capable of producing a signal responsive to light attenuated by tissue at a measurement site. The device may comprise an optical source and a plurality of photodetectors. The optical source is configured to emit optical radiation at least at wavelengths

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between about 1600 nm and about 1700 nm. The photodetectors are configured to detect the optical radiation from said optical source after attenuation by the tissue of the measurement site and each output a respective signal stream responsive to the detected optical radiation.

In an embodiment, a noninvasive, physiological sensor is capable of outputting a signal responsive to a blood analyte present in a monitored patient. The sensor may comprise a sensor housing, an optical source, and photodetectors. The optical source is positioned by the housing with respect to a 10 tissue site of a patient when said housing is applied to the patient. The photodetectors are positioned by the housing with respect to said tissue site when the housing is applied to the patient with a variation in path length among at least some of the photodetectors from the optical source. The 15 photodetectors are configured to detect a sequence of optical radiation from the optical source after attenuation by tissue of the tissue site. The photodetectors may be each configured to output a respective signal stream responsive to the detected sequence of optical radiation. An output signal 20 responsive to one or more of the signal streams is then usable to determine the blood analyte based at least in part on the variation in path length.

In an embodiment, a method of measuring an analyte based on multiple streams of optical radiation measured 25 from a measurement site is provided. A sequence of optical radiation pulses is emitted to the measurement site. At a first location, a first stream of optical radiation is detected from the measurement site. At least at one additional location different from the first location, an additional stream of 30 optical radiation is detected from the measurement site. An output measurement value indicative of the analyte is then determined based on the detected streams of optical radiation.

In various embodiments, the present disclosure relates to 35 an interface for a noninvasive sensor that comprises a front-end adapted to receive an input signals from optical detectors and provide corresponding output signals. In an embodiment, the front-end is comprised of switched-capacitor circuits that are capable of handling multiple streams of 40 signals from the optical detectors. In another embodiment, the front-end comprises transimpedance amplifiers that are capable of handling multiple streams of input signals. In addition, the transimpedance amplifiers may be configured based on the characteristics of the transimpedance amplifier 45 itself, the characteristics of the photodiodes, and the number of photodiodes coupled to the transimpedance amplifier.

In disclosed embodiments, the front-ends are employed in noninvasive sensors to assist in measuring and detecting various analytes. The disclosed noninvasive sensor may also 50 include, among other things, emitters and detectors positioned to produce multi-stream sensor information. An artisan will recognize that the noninvasive sensor may have different architectures and may include or be coupled to other components, such as a display device, a network 55 interface, and the like. An artisan will also recognize that the front-ends may be employed in any type of noninvasive sensor.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to 60 receive signals from a plurality of detectors in the sensor; a set of transimpedance amplifiers configured to convert the signals from the plurality of detectors into an output signal having a stream for each of the plurality of detectors; and an output configured to provide the output signal.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to

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receive signals from a plurality of detectors in the sensor; a set of switched capacitor circuits configured to convert the signals from the plurality of detectors into a digital output signal having a stream for each of the plurality of detectors; and an output configured to provide the digital output signal.

In an embodiment, a conversion processor for a physiological, noninvasive sensor comprises: a multi-stream input configured to receive signals from a plurality of detectors in the sensor, wherein the signals are responsive to optical radiation from a tissue site; a modulator that converts the multi-stream input into a digital bit-stream; and a signal processor that produces an output signal from the digital bit-stream.

In an embodiment, a front-end interface for a noninvasive, physiological sensor comprises: a set of inputs configured to receive signals from a plurality of detectors in the sensor; a set of respective transimpedance amplifiers for each detector configured to convert the signals from the plurality of detectors into an output signal having a stream for each of the plurality of detectors; and an output configured to provide the output signal.

In certain embodiments, a noninvasive sensor interfaces with tissue at a measurement site and deforms the tissue in a way that increases signal gain in certain desired wavelengths.

In some embodiments, a detector for the sensor may comprise a set of photodiodes that are arranged in a spatial configuration. This spatial configuration may allow, for example, signal analysis for measuring analytes like glucose. In various embodiments, the detectors can be arranged across multiple locations in a spatial configuration. The spatial configuration provides a geometry having a diversity of path lengths among the detectors. For example, the detector in the sensor may comprise multiple detectors that are arranged to have a sufficient difference in mean path length to allow for noise cancellation and noise reduction.

In an embodiment, a physiological, noninvasive detector is configured to detect optical radiation from a tissue site. The detector comprises a set of photodetectors and a conversion processor. The set of photodetectors each provide a signal stream indicating optical radiation from the tissue site. The set of photodetectors are arranged in a spatial configuration that provides a variation in path lengths between at least some of the photodetectors. The conversion processor that provides information indicating an analyte in the tissue site based on ratios of pairs of the signal streams.

The present disclosure, according to various embodiments, relates to noninvasive methods, devices, and systems for measuring a blood analyte, such as glucose. In the present disclosure, blood analytes are measured noninvasively based on multi-stream infrared and near-infrared spectroscopy. In some embodiments, an emitter may include one or more sources that are configured as a point optical source. In addition, the emitter may be operated in a manner that allows for the measurement of an analyte like glucose. In embodiments, the emitter may comprise a plurality of LEDs that emit a sequence of pulses of optical radiation across a spectrum of wavelengths. In addition, in order to achieve the desired SNR for detecting analytes like glucose, the emitter may be driven using a progression from low power to higher power. The emitter may also have its duty cycle modified to achieve a desired SNR.

In an embodiment, a multi-stream emitter for a noninvasive, physiological device configured to transmit optical radiation in a tissue site comprises: a set of optical sources arranged as a point optical source; and a driver configured to drive the at least one light emitting diode and at least one

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optical source to transmit near-infrared optical radiation at sufficient power to measure an analyte in tissue that responds to near-infrared optical radiation.

In an embodiment, an emitter for a noninvasive, physiological device configured to transmit optical radiation in a tissue site comprises: a point optical source comprising an optical source configured to transmit infrared and near-infrared optical radiation to a tissue site; and a driver configured to drive the point optical source at a sufficient power and noise tolerance to effectively provide attenuated optical radiation from a tissue site that indicates an amount of glucose in the tissue site.

In an embodiment, a method of transmitting a stream of pulses of optical radiation in a tissue site is provided. At least one pulse of infrared optical radiation having a first pulse width is transmitted at a first power. At least one pulse of near-infrared optical radiation is transmitted at a power that is higher than the first power.

In an embodiment, a method of transmitting a stream of 20 pulses of optical radiation in a tissue site is provided. At least one pulse of infrared optical radiation having a first pulse width is transmitted at a first power. At least one pulse of near-infrared optical radiation is then transmitted, at a second power that is higher than the first power.

For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the inventions disclosed herein. Thus, the inventions disclosed herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as can be taught or suggested herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Throughout the drawings, reference numbers can be reused to indicate correspondence between referenced ele- 40 ments. The drawings are provided to illustrate embodiments of the inventions described herein and not to limit the scope thereof.

FIG. 1 illustrates a block diagram of an example data collection system capable of noninvasively measuring one 45 or more blood analytes in a monitored patient, according to an embodiment of the disclosure;

FIGS. 2A-2D illustrate an exemplary handheld monitor and an exemplary noninvasive optical sensor of the patient monitoring system of FIG. 1, according to embodiments of 50 the disclosure;

FIGS. 3A-3C illustrate side and perspective views of an exemplary noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

FIG. 3D illustrates a side view of another example noninvasive sensor housing including a heat sink, according to an embodiment of the disclosure:

FIG. 3E illustrates a perspective view of an example noninvasive sensor detector shell including example detectors, according to an embodiment of the disclosure;

FIG. 3F illustrates a side view of an example noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

FIGS. 4A through 4C illustrate top elevation, side and top 65 perspective views of an example protrusion, according to an embodiment of the disclosure;

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FIG. 5 illustrates an example graph depicting possible effects of a protrusion on light transmittance, according to an embodiment of the disclosure;

FIGS. 6A through 6D illustrate perspective, front elevation, side and top views of another example protrusion, according to an embodiment of the disclosure;

FIG. 6E illustrates an example sensor incorporating the protrusion of FIGS. 6A through 6D, according to an embodiment of the disclosure;

FIGS. 7A through 7B illustrate example arrangements of conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

FIGS. 8A through 8D illustrate an example top elevation view, side views, and a bottom elevation view of the conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

FIG. 9 shows example comparative results obtained by an embodiment of a sensor;

FIGS. **10**A and **10**B illustrate comparative noise floors of various embodiments of the present disclosure;

FIG. 11A illustrates an exemplary emitter that may be employed in the sensor, according to an embodiment of the disclosure:

FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring blood constituents, according to an embodiment of the disclosure;

FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

FIG. 12A illustrates an example detector portion that may be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

FIGS. **12**B through **12**D illustrate exemplary arrangements of detectors that may be employed in an embodiment of the sensor, according to some embodiments of the disclosure;

FIGS. 12E through 12H illustrate exemplary structures of photodiodes that may be employed in embodiments of the detectors, according to some embodiments of the disclosure;

FIG. 13 illustrates an example multi-stream operation of the system of FIG. 1, according to an embodiment of the disclosure;

FIG. **14**A illustrates another example detector portion having a partially cylindrical protrusion that can be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

FIG. 14B depicts a front elevation view of the partially cylindrical protrusion of FIG. 14A;

FIGS. 14C through 14E illustrate embodiments of a 55 detector submount;

FIGS. 14F through 14H illustrate embodiment of portions of a detector shell;

FIG. **14**I illustrates a cutaway view of an embodiment of a sensor;

FIGS. 15A through 15F illustrate embodiments of sensors that include heat sink features;

FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described herein:

FIG. **15**I illustrates an exemplary architecture for a transimpedance-based front-end that may be employed in any of the sensors described herein;

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FIG. **15**J illustrates an exemplary noise model for configuring the transimpedance-based front-ends shown in FIG. **15**I:

FIG. 15K shows different architectures and layouts for various embodiments of a sensor and its detectors;

FIG. **15**L illustrates an exemplary architecture for a switched-capacitor-based front-end that may be employed in any of the sensors described herein;

FIGS. 16A and 16B illustrate embodiments of disposable optical sensors;

FIG. 17 illustrates an exploded view of certain components of an example sensor; and

FIGS. 18 through 22 illustrate various results obtained by an exemplary sensor of the disclosure.

#### DETAILED DESCRIPTION

The present disclosure generally relates to non-invasive medical devices. In the present disclosure, a sensor can measure various blood constituents or analytes noninvasively using multi-stream spectroscopy. In an embodiment, the multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes or percentages thereof (e.g., saturation) based on various 25 combinations of features and components.

In various embodiments, the present disclosure relates to an interface for a noninvasive glucose sensor that comprises a front-end adapted to receive an input signals from optical detectors and provide corresponding output signals. The 30 front-end may comprise, among other things, switched capacitor circuits or transimpedance amplifiers. In an embodiment, the front-end may comprise switched capacitor circuits that are configured to convert the output of sensor's detectors into a digital signal. In another embodiment, the 35 front-end may comprise transimpedance amplifiers. These transimpedance amplifiers may be configured to match one or more photodiodes in a detector based on a noise model that accounts for characteristics, such as the impedance, of the transimpedance amplifier, characteristics of each photo- 40 diode, such as the impedance, and the number of photodiodes coupled to the transimpedance amplifier.

In the present disclosure, the front-ends are employed in a sensor that measures various blood analytes noninvasively using multi-stream spectroscopy. In an embodiment, the 45 multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes, such as glucose, total hemoglobin, methemoglobin, oxygen content, and the like, based on various combinations of features and 50 components.

In an embodiment, a physiological sensor includes a detector housing that can be coupled to a measurement site, such as a patient's finger. The sensor housing can include a curved bed that can generally conform to the shape of the 55 measurement site. In addition, the curved bed can include a protrusion shaped to increase an amount of light radiation from the measurement site. In an embodiment, the protrusion is used to thin out the measurement site. This allows the light radiation to pass through less tissue, and accordingly is 60 attenuated less. In an embodiment, the protrusion can be used to increase the area from which attenuated light can be measured. In an embodiment, this is done through the use of a lens which collects attenuated light exiting the measurement site and focuses onto one or more detectors. The 65 protrusion can advantageously include plastic, including a hard opaque plastic, such as a black or other colored plastic,

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helpful in reducing light noise. In an embodiment, such light noise includes light that would otherwise be detected at a photodetector that has not been attenuated by tissue of the measurement site of a patient sufficient to cause the light to adequately included information indicative of one or more physiological parameters of the patient. Such light noise includes light piping.

In an embodiment, the protrusion can be formed from the curved bed, or can be a separate component that is positionable with respect to the bed. In an embodiment, a lens made from any appropriate material is used as the protrusion. The protrusion can be convex in shape. The protrusion can also be sized and shaped to conform the measurement site into a flat or relatively flat surface. The protrusion can also be sized to conform the measurement site into a rounded surface, such as, for example, a concave or convex surface. The protrusion can include a cylindrical or partially cylindrical shape. The protrusion can be sized or shaped differently for different types of patients, such as an adult, child, or infant. The protrusion can also be sized or shaped differently for different measurement sites, including, for example, a finger, toe, hand, foot, ear, forehead, or the like. The protrusion can thus be helpful in any type of noninvasive sensor. The external surface of the protrusion can include one or more openings or windows. The openings can be made from glass to allow attenuated light from a measurement site, such as a finger, to pass through to one or more detectors. Alternatively, some of all of the protrusion can be a lens, such as a partially cylindrical lens.

The sensor can also include a shielding, such as a metal enclosure as described below or embedded within the protrusion to reduce noise. The shielding can be constructed from a conductive material, such as copper, in the form of a metal cage or enclosure, such as a box. The shielding can include a second set of one or more openings or windows. The second set of openings can be made from glass and allow light that has passed through the first set of windows of the external surface of the protrusion to pass through to one or more detectors that can be enclosed, for example, as described below.

In various embodiments, the shielding can include any substantially transparent, conductive material placed in the optical path between an emitter and a detector. The shielding can be constructed from a transparent material, such as glass, plastic, and the like. The shielding can have an electrically conductive material or coating that is at least partially transparent. The electrically conductive coating can be located on one or both sides of the shielding, or within the body of the shielding. In addition, the electrically conductive coating can be uniformly spread over the shielding or may be patterned. Furthermore, the coating can have a uniform or varying thickness to increase or optimize its shielding effect. The shielding can be helpful in virtually any type of non-invasive sensor that employs spectroscopy.

In an embodiment, the sensor can also include a heat sink. In an embodiment, the heat sink can include a shape that is functional in its ability to dissipate excess heat and aesthetically pleasing to the wearer. For example, the heat sink can be configured in a shape that maximizes surface area to allow for greater dissipation of heat. In an embodiment, the heat sink includes a metalicized plastic, such as plastic including carbon and aluminum to allow for improved thermal conductivity and diffusivity. In an embodiment, the heat sink can advantageously be inexpensively molded into desired shapes and configurations for aesthetic and functional purposes. For example, the shape of the heat sink can

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be a generally curved surface and include one or more fins, undulations, grooves or channels, or combs.

The sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter can include a plurality of sets of optical sources that, 5 in an embodiment, are arranged together as a point source. The various optical sources can emit a sequence of optical radiation pulses at different wavelengths towards a measurement site, such as a patient's finger. Detectors can then detect optical radiation from the measurement site. The 10 optical sources and optical radiation detectors can operate at any appropriate wavelength, including, as discussed herein, infrared, near infrared, visible light, and ultraviolet. In addition, the optical sources and optical radiation detectors can operate at any appropriate wavelength, and such modifications to the embodiments desirable to operate at any such wavelength will be apparent to those skilled in the art.

In certain embodiments, multiple detectors are employed and arranged in a spatial geometry. This spatial geometry provides a diversity of path lengths among at least some of 20 the detectors and allows for multiple bulk and pulsatile measurements that are robust. Each of the detectors can provide a respective output stream based on the detected optical radiation, or a sum of output streams can be provided from multiple detectors. In some embodiments, the sensor 25 can also include other components, such as one or more heat sinks and one or more thermistors.

The spatial configuration of the detectors provides a geometry having a diversity of path lengths among the detectors. For example, a detector in the sensor may comprise multiple detectors that are arranged to have a sufficient difference in mean path length to allow for noise cancellation and noise reduction. In addition, walls may be used to separate individual photodetectors and prevent mixing of detected optical radiation between the different locations on 35 the measurement site. A window may also be employed to facilitate the passing of optical radiation at various wavelengths for measuring glucose in the tissue.

In the present disclosure, a sensor may measure various blood constituents or analytes noninvasively using spectroscopy and a recipe of various features. As disclosed herein, the sensor is capable of non-invasively measuring blood analytes, such as, glucose, total hemoglobin, methemoglobin, oxygen content, and the like. In an embodiment, the spectroscopy used in the sensor can employ visible, infrared 45 and near infrared wavelengths. The sensor may comprise an emitter, a detector, and other components. In some embodiments, the sensor may also comprise other components, such as one or more heat sinks and one or more thermistors.

In various embodiments, the sensor may also be coupled 50 to one or more companion devices that process and/or display the sensor's output. The companion devices may comprise various components, such as a sensor front-end, a signal processor, a display, a network interface, a storage device or memory, etc. 55

A sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter is configured as a point optical source that comprises a plurality of LEDs that emit a sequence of pulses of optical radiation across a spectrum of wavelengths. In some 60 embodiments, the plurality of sets of optical sources may each comprise at least one top-emitting LED and at least one super luminescent LED. In some embodiments, the emitter comprises optical sources that transmit optical radiation in the infrared or near-infrared wavelengths suitable for detecting blood analytes like glucose. In order to achieve the desired SNR for detecting analytes like glucose, the emitter

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may be driven using a progression from low power to higher power. In addition, the emitter may have its duty cycle modified to achieve a desired SNR.

The emitter may be constructed of materials, such as aluminum nitride and may include a heat sink to assist in heat dissipation. A thermistor may also be employed to account for heating effects on the LEDs. The emitter may further comprise a glass window and a nitrogen environment to improve transmission from the sources and prevent oxidative effects.

The sensor can be coupled to one or more monitors that process and/or display the sensor's output. The monitors can include various components, such as a sensor front end, a signal processor, a display, etc.

The sensor can be integrated with a monitor, for example, into a handheld unit including the sensor, a display and user controls. In other embodiments, the sensor can communicate with one or more processing devices. The communication can be via wire(s), cable(s), flex circuit(s), wireless technologies, or other suitable analog or digital communication methodologies and devices to perform those methodologies. Many of the foregoing arrangements allow the sensor to be attached to the measurement site while the device is attached elsewhere on a patient, such as the patient's arm, or placed at a location near the patient, such as a bed, shelf or table. The sensor or monitor can also provide outputs to a storage device or network interface.

Reference will now be made to the Figures to discuss embodiments of the present disclosure.

FIG. 1 illustrates an example of a data collection system 100. In certain embodiments, the data collection system 100 noninvasively measure a blood analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. The system 100 can also measure additional blood analytes and/or other physiological parameters useful in determining a state or trend of wellness of a patient.

The data collection system 100 can be capable of measuring optical radiation from the measurement site. For example, in some embodiments, the data collection system 100 can employ photodiodes defined in terms of area. In an embodiment, the area is from about 1 mm²-5 mm² (or higher) that are capable of detecting about 100 nanoamps (nA) or less of current resulting from measured light at full scale. In addition to having its ordinary meaning, the phrase "at full scale" can mean light saturation of a photodiode amplifier (not shown). Of course, as would be understood by a person of skill in the art from the present disclosure, various other sizes and types of photodiodes can be used with the embodiments of the present disclosure.

The data collection system 100 can measure a range of approximately about 2 nA to about 100 nA full scale. The data collection system 100 can also include sensor frontends that are capable of processing and amplifying current from the detector(s) at signal-to-noise ratios (SNRs) of about 100 decibels (dB) or more, such as about 120 dB in order to measure various desired analytes. The data collection system 100 can operate with a lower SNR if less accuracy is desired for an analyte like glucose.

The data collection system 100 can measure analyte concentrations, including glucose, at least in part by detecting light attenuated by a measurement site 102. The measurement site 102 can be any location on a patient's body, such as a finger, foot, ear lobe, or the like. For convenience, this disclosure is described primarily in the context of a

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finger measurement site 102. However, the features of the embodiments disclosed herein can be used with other measurement sites 102.

In the depicted embodiment, the system 100 includes an optional tissue thickness adjuster or tissue shaper 105, which 5 can include one or more protrusions, bumps, lenses, or other suitable tissue-shaping mechanisms. In certain embodiments, the tissue shaper 105 is a flat or substantially flat surface that can be positioned proximate the measurement site 102 and that can apply sufficient pressure to cause the 10 tissue of the measurement site 102 to be flat or substantially flat. In other embodiments, the tissue shaper 105 is a convex or substantially convex surface with respect to the measurement site 102. Many other configurations of the tissue shaper 105 are possible. Advantageously, in certain embodiments, 15 the tissue shaper 105 reduces thickness of the measurement site 102 while preventing or reducing occlusion at the measurement site 102. Reducing thickness of the site can advantageously reduce the amount of attenuation of the light because there is less tissue through which the light must 20 travel. Shaping the tissue in to a convex (or alternatively concave) surface can also provide more surface area from which light can be detected.

The embodiment of the data collection system 100 shown also includes an optional noise shield 103. In an embodi- 25 ment, the noise shield 103 can be advantageously adapted to reduce electromagnetic noise while increasing the transmittance of light from the measurement site 102 to one or more detectors 106 (described below). For example, the noise shield 103 can advantageously include a conductive coated 30 glass or metal grid electrically communicating with one or more other shields of the sensor 101 or electrically grounded. In an embodiment where the noise shield 103 includes conductive coated glass, the coating can advantageously include indium tin oxide. In an embodiment, the 35 indium tin oxide includes a surface resistivity ranging from approximately 30 ohms per square inch to about 500 ohms per square inch. In an embodiment, the resistivity is approximately 30, 200, or 500 ohms per square inch. As would be understood by a person of skill in the art from the present 40 disclosure, other resistivities can also be used which are less than about 30 ohms or more than about 500 ohms. Other conductive materials transparent or substantially transparent to light can be used instead.

In some embodiments, the measurement site **102** is 45 located somewhere along a non-dominant arm or a non-dominant hand, e.g., a right-handed person's left arm or left hand. In some patients, the non-dominant arm or hand can have less musculature and higher fat content, which can result in less water content in that tissue of the patient. Tissue 50 having less water content can provide less interference with the particular wavelengths that are absorbed in a useful manner by blood analytes like glucose. Accordingly, in some embodiments, the data collection system **100** can be used on a person's non-dominant hand or arm.

The data collection system 100 can include a sensor 101 (or multiple sensors) that is coupled to a processing device or physiological monitor 109. In an embodiment, the sensor 101 and the monitor 109 are integrated together into a single unit. In another embodiment, the sensor 101 and the monitor 60 109 are separate from each other and communicate one with another in any suitable manner, such as via a wired or wireless connection. The sensor 101 and monitor 109 can be attachable and detachable from each other for the convenience of the user or caregiver, for ease of storage, sterility 65 issues, or the like. The sensor 101 and the monitor 109 will now be further described.

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In the depicted embodiment shown in FIG. 1, the sensor 101 includes an emitter 104, a tissue shaper 105, a set of detectors 106, and a front-end interface 108. The emitter 104 can serve as the source of optical radiation transmitted towards measurement site 102. As will be described in further detail below, the emitter 104 can include one or more sources of optical radiation, such as LEDs, laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter 104 includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation.

In some embodiments, the emitter 104 is used as a point optical source, and thus, the one or more optical sources of the emitter 104 can be located within a close distance to each other, such as within about a 2 mm to about 4 mm. The emitters 104 can be arranged in an array, such as is described in U.S. Publication No. 2006/0211924, filed Sep. 21, 2006, titled "Multiple Wavelength Sensor Emitters," the disclosure of which is hereby incorporated by reference in its entirety. In particular, the emitters 104 can be arranged at least in part as described in paragraphs [0061] through [0068] of the aforementioned publication, which paragraphs are hereby incorporated specifically by reference. Other relative spatial relationships can be used to arrange the emitters 104.

For analytes like glucose, currently available non-invasive techniques often attempt to employ light near the water absorbance minima at or about 1600 nm. Typically, these devices and methods employ a single wavelength or single band of wavelengths at or about 1600 nm. However, to date, these techniques have been unable to adequately consistently measure analytes like glucose based on spectroscopy.

In contrast, the emitter 104 of the data collection system 100 can emit, in certain embodiments, combinations of optical radiation in various bands of interest. For example, in some embodiments, for analytes like glucose, the emitter 104 can emit optical radiation at three (3) or more wavelengths between about 1600 nm to about 1700 nm. In particular, the emitter 104 can emit optical radiation at or about 1610 nm, about 1640 nm, and about 1665 nm. In some circumstances, the use of three wavelengths within about 1600 nm to about 1700 nm enable sufficient SNRs of about 100 dB, which can result in a measurement accuracy of about 20 mg/dL or better for analytes like glucose.

In other embodiments, the emitter 104 can use two (2) wavelengths within about 1600 nm to about 1700 nm to advantageously enable SNRs of about 85 dB, which can result in a measurement accuracy of about 25-30 mg/dL or better for analytes like glucose. Furthermore, in some embodiments, the emitter 104 can emit light at wavelengths above about 1670 nm. Measurements at these wavelengths can be advantageously used to compensate or confirm the contribution of protein, water, and other non-hemoglobin species exhibited in measurements for analytes like glucose conducted between about 1600 nm and about 1700 nm. Of course, other wavelengths and combinations of wavelengths can be used to measure analytes and/or to distinguish other types of tissue, fluids, tissue properties, fluid properties, combinations of the same or the like.

For example, the emitter 104 can emit optical radiation across other spectra for other analytes. In particular, the emitter 104 can employ light wavelengths to measure various blood analytes or percentages (e.g., saturation) thereof. For example, in one embodiment, the emitter 104 can emit optical radiation in the form of pulses at wavelengths about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about

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1665 nm. In another embodiment, the emitter **104** can emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of 5 course, the emitter **104** can transmit any of a variety of wavelengths of visible or near-infrared optical radiation.

Due to the different responses of analytes to the different wavelengths, certain embodiments of the data collection system 100 can advantageously use the measurements at 10 these different wavelengths to improve the accuracy of measurements. For example, the measurements of water from visible and infrared light can be used to compensate for water absorbance that is exhibited in the near-infrared wavelengths

As briefly described above, the emitter 104 can include sets of light-emitting diodes (LEDs) as its optical source. The emitter 104 can use one or more top-emitting LEDs. In particular, in some embodiments, the emitter 104 can include top-emitting LEDs emitting light at about 850 nm to 20 1350 nm.

The emitter 104 can also use super luminescent LEDs (SLEDs) or side-emitting LEDs. In some embodiments, the emitter 104 can employ SLEDs or side-emitting LEDs to emit optical radiation at about 1600 nm to about 1800 nm. 25 Emitter 104 can use SLEDs or side-emitting LEDs to transmit near infrared optical radiation because these types of sources can transmit at high power or relatively high power, e.g., about 40 mW to about 100 mW. This higher power capability can be useful to compensate or overcome 30 the greater attenuation of these wavelengths of light in tissue and water. For example, the higher power emission can effectively compensate and/or normalize the absorption signal for light in the mentioned wavelengths to be similar in amplitude and/or effect as other wavelengths that can be 35 detected by one or more photodetectors after absorption. However, the embodiments of the present disclosure do not necessarily require the use of high power optical sources. For example, some embodiments may be configured to measure analytes, such as total hemoglobin (tHb), oxygen 40 saturation (SpO<sub>2</sub>), carboxyhemoglobin, methemoglobin, etc., without the use of high power optical sources like side emitting LEDs. Instead, such embodiments may employ other types of optical sources, such as top emitting LEDs. Alternatively, the emitter **104** can use other types of sources 45 of optical radiation, such as a laser diode, to emit nearinfrared light into the measurement site 102.

In addition, in some embodiments, in order to assist in achieving a comparative balance of desired power output between the LEDs, some of the LEDs in the emitter **104** can 50 have a filter or covering that reduces and/or cleans the optical radiation from particular LEDs or groups of LEDs. For example, since some wavelengths of light can penetrate through tissue relatively well, LEDs, such as some or all of the top-emitting LEDs can use a filter or covering, such as a cap or painted dye. This can be useful in allowing the emitter **104** to use LEDs with a higher output and/or to equalize intensity of LEDs.

The data collection system 100 also includes a driver 111 that drives the emitter 104. The driver 111 can be a circuit 60 or the like that is controlled by the monitor 109. For example, the driver 111 can provide pulses of current to the emitter 104. In an embodiment, the driver 111 drives the emitter 104 in a progressive fashion, such as in an alternating manner. The driver 111 can drive the emitter 104 with a 65 series of pulses of about 1 milliwatt (mW) for some wavelengths that can penetrate tissue relatively well and from

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about 40 mW to about 100 mW for other wavelengths that tend to be significantly absorbed in tissue. A wide variety of other driving powers and driving methodologies can be used in various embodiments.

The driver 111 can be synchronized with other parts of the sensor 101 and can minimize or reduce jitter in the timing of pulses of optical radiation emitted from the emitter 104. In some embodiments, the driver 111 is capable of driving the emitter 104 to emit optical radiation in a pattern that varies by less than about 10 parts-per-million.

The detectors 106 capture and measure light from the measurement site 102. For example, the detectors 106 can capture and measure light transmitted from the emitter 104 that has been attenuated or reflected from the tissue in the measurement site 102. The detectors 106 can output a detector signal 107 responsive to the light captured or measured. The detectors 106 can be implemented using one or more photodiodes, phototransistors, or the like.

In addition, the detectors 106 can be arranged with a spatial configuration to provide a variation of path lengths among at least some of the detectors 106. That is, some of the detectors 106 can have the substantially, or from the perspective of the processing algorithm, effectively, the same path length from the emitter 104. However, according to an embodiment, at least some of the detectors 106 can have a different path length from the emitter 104 relative to other of the detectors 106. Variations in path lengths can be helpful in allowing the use of a bulk signal stream from the detectors 106. In some embodiments, the detectors 106 may employ a linear spacing, a logarithmic spacing, or a two or three dimensional matrix of spacing, or any other spacing scheme in order to provide an appropriate variation in path lengths.

The front end interface 108 provides an interface that adapts the output of the detectors 106, which is responsive to desired physiological parameters. For example, the front end interface 108 can adapt a signal 107 received from one or more of the detectors 106 into a form that can be processed by the monitor 109, for example, by a signal processor 110 in the monitor 109. The front end interface 108 can have its components assembled in the sensor 101, in the monitor 109, in connecting cabling (if used), combinations of the same, or the like. The location of the front end interface 108 can be chosen based on various factors including space desired for components, desired noise reductions or limits, desired heat reductions or limits, and the like.

The front end interface 108 can be coupled to the detectors 106 and to the signal processor 110 using a bus, wire, electrical or optical cable, flex circuit, or some other form of signal connection. The front end interface 108 can also be at least partially integrated with various components, such as the detectors 106. For example, the front end interface 108 can include one or more integrated circuits that are on the same circuit board as the detectors 106. Other configurations can also be used.

The front end interface 108 can be implemented using one or more amplifiers, such as transimpedance amplifiers, that are coupled to one or more analog to digital converters (ADCs) (which can be in the monitor 109), such as a sigma-delta ADC. A transimpedance-based front end interface 108 can employ single-ended circuitry, differential circuitry, and/or a hybrid configuration. A transimpedance-based front end interface 108 can be useful for its sampling rate capability and freedom in modulation/demodulation algorithms. For example, this type of front end interface 108

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can advantageously facilitate the sampling of the ADCs being synchronized with the pulses emitted from the emitter 104

The ADC or ADCs can provide one or more outputs into multiple channels of digital information for processing by the signal processor 110 of the monitor 109. Each channel can correspond to a signal output from a detector 106.

In some embodiments, a programmable gain amplifier (PGA) can be used in combination with a transimpedance-based front end interface 108. For example, the output of a transimpedance-based front end interface 108 can be output to a PGA that is coupled with an ADC in the monitor 109. A PGA can be useful in order to provide another level of amplification and control of the stream of signals from the detectors 106. Alternatively, the PGA and ADC components can be integrated with the transimpedance-based front end interface 108 in the sensor 101.

In another embodiment, the front end interface 108 can be implemented using switched-capacitor circuits. A switched-capacitor-based front end interface 108 can be useful for, in certain embodiments, its resistor-free design and analog averaging properties. In addition, a switched-capacitor-based front end interface 108 can be useful because it can provide a digital signal to the signal processor 110 in the 25 monitor 109.

As shown in FIG. 1, the monitor 109 can include the signal processor 110 and a user interface, such as a display 112. The monitor 109 can also include optional outputs alone or in combination with the display 112, such as a 30 storage device 114 and a network interface 116. In an embodiment, the signal processor 110 includes processing logic that determines measurements for desired analytes, such as glucose, based on the signals received from the detectors 106. The signal processor 110 can be implemented 35 using one or more microprocessors or subprocessors (e.g., cores), digital signal processors, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), combinations of the same, and the like.

The signal processor 110 can provide various signals that 40 control the operation of the sensor 101. For example, the signal processor 110 can provide an emitter control signal to the driver 111. This control signal can be useful in order to synchronize, minimize, or reduce jitter in the timing of pulses emitted from the emitter 104. Accordingly, this 45 control signal can be useful in order to cause optical radiation pulses emitted from the emitter 104 to follow a precise timing and consistent pattern. For example, when a transimpedance-based front end interface 108 is used, the control signal from the signal processor 110 can provide synchro- 50 nization with the ADC in order to avoid aliasing, cross-talk, and the like. As also shown, an optional memory 113 can be included in the front-end interface 108 and/or in the signal processor 110. This memory 113 can serve as a buffer or storage location for the front-end interface 108 and/or the 55 signal processor 110, among other uses.

The user interface 112 can provide an output, e.g., on a display, for presentation to a user of the data collection system 100. The user interface 112 can be implemented as a touch-screen display, an LCD display, an organic LED 60 display, or the like. In addition, the user interface 112 can be manipulated to allow for measurement on the non-dominant side of patient. For example, the user interface 112 can include a flip screen, a screen that can be moved from one side to another on the monitor 109, or can include an ability 65 to reorient its display indicia responsive to user input or device orientation. In alternative embodiments, the data

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collection system 100 can be provided without a user interface 112 and can simply provide an output signal to a separate display or system.

A storage device 114 and a network interface 116 represent other optional output connections that can be included in the monitor 109. The storage device 114 can include any computer-readable medium, such as a memory device, hard disk storage, EEPROM, flash drive, or the like. The various software and/or firmware applications can be stored in the storage device 114, which can be executed by the signal processor 110 or another processor of the monitor 109. The network interface 116 can be a serial bus port (RS-232/RS-485), a Universal Serial Bus (USB) port, an Ethernet port, a wireless interface (e.g., WiFi such as any 802.1x interface, including an internal wireless card), or other suitable communication device(s) that allows the monitor 109 to communicate and share data with other devices. The monitor 109 can also include various other components not shown, such as a microprocessor, graphics processor, or controller to output the user interface 112, to control data communications, to compute data trending, or to perform other opera-

Although not shown in the depicted embodiment, the data collection system 100 can include various other components or can be configured in different ways. For example, the sensor 101 can have both the emitter 104 and detectors 106 on the same side of the measurement site 102 and use reflectance to measure analytes. The data collection system 100 can also include a sensor that measures the power of light emitted from the emitter 104.

FIGS. 2A through 2D illustrate example monitoring devices 200 in which the data collection system 100 can be housed. Advantageously, in certain embodiments, some or all of the example monitoring devices 200 shown can have a shape and size that allows a user to operate it with a single hand or attach it, for example, to a patient's body or limb. Although several examples are shown, many other monitoring device configurations can be used to house the data collection system 100. In addition, certain of the features of the monitoring devices 200 shown in FIGS. 2A through 2D can be combined with features of the other monitoring devices 200 shown.

Referring specifically to FIG. 2A, an example monitoring device 200A is shown, in which a sensor 201a and a monitor 209a are integrated into a single unit. The monitoring device 200A shown is a handheld or portable device that can measure glucose and other analytes in a patient's finger. The sensor 201a includes an emitter shell 204a and a detector shell 206a. The depicted embodiment of the monitoring device 200A also includes various control buttons 208a and a display 210a.

The sensor 201a can be constructed of white material used for reflective purposes (such as white silicone or plastic), which can increase the usable signal at the detector 106 by forcing light back into the sensor 201a. Pads in the emitter shell 204a and the detector shell 206a can contain separated windows to prevent or reduce mixing of light signals, for example, from distinct quadrants on a patient's finger. In addition, these pads can be made of a relatively soft material, such as a gel or foam, in order to conform to the shape, for example, of a patient's finger. The emitter shell 204a and the detector shell 206a can also include absorbing black or grey material portions to prevent or reduce ambient light from entering into the sensor 201a.

In some embodiments, some or all portions of the emitter shell **204***a* and/or detector shell **206***a* can be detachable and/or disposable. For example, some or all portions of the

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shells 204a and 206a can be removable pieces. The removability of the shells 204a and 206a can be useful for sanitary purposes or for sizing the sensor 201a to different patients. The monitor 209a can include a fitting, slot, magnet, or other connecting mechanism to allow the sensor 201c to be 5 removably attached to the monitor 209a.

The monitoring device **200***a* also includes optional control buttons **208***a* and a display **210***a* that can allow the user to control the operation of the device. For example, a user can operate the control buttons **208***a* to view one or more 10 measurements of various analytes, such as glucose. In addition, the user can operate the control buttons **208***a* to view other forms of information, such as graphs, histograms, measurement data, trend measurement data, parameter combination views, wellness indications, and the like. Many 15 parameters, trends, alarms and parameter displays could be output to the display **210***a*, such as those that are commercially available through a wide variety of noninvasive monitoring devices from Masimo® Corporation of Irvine, Calif.

Furthermore, the controls **208***a* and/or display **210***a* can 20 provide functionality for the user to manipulate settings of the monitoring device **200***a*, such as alarm settings, emitter settings, detector settings, and the like. The monitoring device **200***a* can employ any of a variety of user interface designs, such as frames, menus, touch-screens, and any type 25 of button.

FIG. 2B illustrates another example of a monitoring device 200B. In the depicted embodiment, the monitoring device 200B includes a finger clip sensor 201b connected to a monitor 209b via a cable 212. In the embodiment shown, 30 the monitor 209b includes a display 210b, control buttons 208b and a power button. Moreover, the monitor 209b can advantageously include electronic processing, signal processing, and data storage devices capable of receiving signal data from said sensor 201b, processing the signal data to 35 determine one or more output measurement values indicative of one or more physiological parameters of a monitored patient, and displaying the measurement values, trends of the measurement values, combinations of measurement values, and the like.

The cable 212 connecting the sensor 201b and the monitor 209b can be implemented using one or more wires, optical fiber, flex circuits, or the like. In some embodiments, the cable 212 can employ twisted pairs of conductors in order to minimize or reduce cross-talk of data transmitted from the 45 sensor 201b to the monitor 209b. Various lengths of the cable 212 can be employed to allow for separation between the sensor 201b and the monitor 209b. The cable 212 can be fitted with a connector (male or female) on either end of the cable 212 so that the sensor 201b and the monitor 209b can 50 be connected and disconnected from each other. Alternatively, the sensor 201b and the monitor 209b can be coupled together via a wireless communication link, such as an infrared link, radio frequency channel, or any other wireless communication protocol and channel.

The monitor 209b can be attached to the patient. For example, the monitor 209b can include a belt clip or straps (see, e.g., FIG. 2C) that facilitate attachment to a patient's belt, arm, leg, or the like. The monitor 209b can also include a fitting, slot, magnet, LEMO snap-click connector, or other connecting mechanism to allow the cable 212 and sensor 201b to be attached to the monitor 209B.

The monitor **209***b* can also include other components, such as a speaker, power button, removable storage or memory (e.g., a flash card slot), an AC power port, and one 65 or more network interfaces, such as a universal serial bus interface or an Ethernet port. For example, the monitor **209***b* 

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can include a display 210b that can indicate a measurement for glucose, for example, in mg/dL. Other analytes and forms of display can also appear on the monitor 209b.

In addition, although a single sensor 201b with a single monitor 209b is shown, different combinations of sensors and device pairings can be implemented. For example, multiple sensors can be provided for a plurality of differing patient types or measurement sites or even patient fingers.

FIG. 2C illustrates yet another example of monitoring device 200C that can house the data collection system 100. Like the monitoring device 200B, the monitoring device 200C includes a finger clip sensor 201c connected to a monitor 209c via a cable 212. The cable 212 can have all of the features described above with respect to FIG. 2B. The monitor 209c can include all of the features of the monitor 200B described above. For example, the monitor 209c includes buttons 208c and a display 210c. The monitor 209c shown also includes straps 214c that allow the monitor 209c to be attached to a patient's limb or the like.

FIG. 2D illustrates vet another example of monitoring device 200D that can house the data collection system 100. Like the monitoring devices 200B and 200C, the monitoring device 200D includes a finger clip sensor 201d connected to a monitor 209d via a cable 212. The cable 212 can have all of the features described above with respect to FIG. 2B. In addition to having some or all of the features described above with respect to FIGS. 2B and 2C, the monitoring device 200D includes an optional universal serial bus (USB) port 216 and an Ethernet port 218. The USB port 216 and the Ethernet port 218 can be used, for example, to transfer information between the monitor 209d and a computer (not shown) via a cable. Software stored on the computer can provide functionality for a user to, for example, view physiological data and trends, adjust settings and download firmware updates to the monitor 209b, and perform a variety of other functions. The USB port 216 and the Ethernet port 218 can be included with the other monitoring devices 200A, 200B, and 200C described above.

FIGS. 3A through 3C illustrate more detailed examples of embodiments of a sensor 301a. The sensor 301a shown can include all of the features of the sensors 100 and 200 described above.

Referring to FIG. 3A, the sensor 301a in the depicted embodiment is a clothespin-shaped clip sensor that includes an enclosure 302a for receiving a patient's finger. The enclosure 302a is formed by an upper section or emitter shell 304a, which is pivotably connected with a lower section or detector shell 306a. The emitter shell 304a can be biased with the detector shell 306a to close together around a pivot point 303a and thereby sandwich finger tissue between the emitter and detector shells 304a, 306a.

In an embodiment, the pivot point 303a advantageously includes a pivot capable of adjusting the relationship between the emitter and detector shells 304a, 306a to effectively level the sections when applied to a tissue site. In another embodiment, the sensor 301a includes some or all features of the finger clip described in U.S. Publication No. 2006/0211924, incorporated above, such as a spring that causes finger clip forces to be distributed along the finger. Paragraphs [0096] through [0105], which describe this feature, are hereby specifically incorporated by reference.

The emitter shell **304***a* can position and house various emitter components of the sensor **301***a*. It can be constructed of reflective material (e.g., white silicone or plastic) and/or can be metallic or include metalicized plastic (e.g., including carbon and aluminum) to possibly serve as a heat sink. The emitter shell **304***a* can also include absorbing opaque mate-

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rial, such as, for example, black or grey colored material, at various areas, such as on one or more flaps 307a, to reduce ambient light entering the sensor 301a.

The detector shell **306***a* can position and house one or more detector portions of the sensor **301***a*. The detector shell **306***a* can be constructed of reflective material, such as white silicone or plastic. As noted, such materials can increase the usable signal at a detector by forcing light back into the tissue and measurement site (see FIG. 1). The detector shell **306***a* can also include absorbing opaque material at various areas, such as lower area **308***a*, to reduce ambient light entering the sensor **301***a*.

Referring to FIGS. 3B and 3C, an example of finger bed 310 is shown in the sensor 301b. The finger bed 310 includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger bed 310 includes one or more ridges or channels 314. Each of the ridges 314 has a generally convex shape that can facilitate increasing traction or gripping of the patient's finger to the finger bed. Advantageously, the ridges 314 can improve the accuracy of spectroscopic analysis in certain embodiments by reducing noise that can result from a measurement site moving or shaking loose inside of the sensor 301a. The ridges 314 can be made from reflective or opaque materials in some 25 embodiments to further increase SNR. In other implementations, other surface shapes can be used, such as, for example, generally flat, concave, or convex finger beds 310.

Finger bed 310 can also include an embodiment of a tissue thickness adjuster or protrusion 305. The protrusion 305 includes a measurement site contact area 370 (see FIG. 3C) that can contact body tissue of a measurement site. The protrusion 305 can be removed from or integrated with the finger bed 310. Interchangeable, different shaped protrusions 305 can also be provided, which can correspond to 35 different finger shapes, characteristics, opacity, sizes, or the like

Referring specifically to FIG. 3C, the contact area 370 of the protrusion 305 can include openings or windows 320, 321, 322, and 323. When light from a measurement site 40 passes through the windows 320, 321, 322, and 323, the light can reach one or more photodetectors (see FIG. 3E). In an embodiment, the windows 320, 321, 322, and 323 mirror specific detector placements layouts such that light can impinge through the protrusion 305 onto the photodetectors. 45 Any number of windows 320, 321, 322, and 323 can be employed in the protrusion 305 to allow light to pass from the measurement site to the photodetectors.

The windows 320, 321, 322, and 323 can also include shielding, such as an embedded grid of wiring or a conduc- 50 tive glass coating, to reduce noise from ambient light or other electromagnetic noise. The windows 320, 321, 322, and 323 can be made from materials, such as plastic or glass. In some embodiments, the windows 320, 321, 322, and 323 can be constructed from conductive glass, such as indium tin 55 oxide (ITO) coated glass. Conductive glass can be useful because its shielding is transparent, and thus allows for a larger aperture versus a window with an embedded grid of wiring. In addition, in certain embodiments, the conductive glass does not need openings in its shielding (since it is transparent), which enhances its shielding performance. For example, some embodiments that employ the conductive glass can attain up to an about 40% to about 50% greater signal than non-conductive glass with a shielding grid. In addition, in some embodiments, conductive glass can be 65 useful for shielding noise from a greater variety of directions than non-conductive glass with a shielding grid.

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Turning to FIG. 3B, the sensor 301a can also include a shielding 315a, such as a metal cage, box, metal sheet, perforated metal sheet, a metal layer on a non-metal material, or the like. The shielding 315a is provided in the depicted embodiment below or embedded within the protrusion 305 to reduce noise. The shielding 315a can be constructed from a conductive material, such as copper. The shielding 315a can include one or more openings or windows (not shown). The windows can be made from glass or plastic to thereby allow light that has passed through the windows 320, 321, 322, and 323 on an external surface of the protrusion 305 (see FIG. 3C) to pass through to one or more photodetectors that can be enclosed or provided below (see FIG. 3E).

In some embodiments, the shielding cage for shielding 315a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding cage can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108.

In an embodiment, the photodetectors can be positioned within or directly beneath the protrusion 305 (see FIG. 3E). In such cases, the mean optical path length from the emitters to the detectors can be reduced and the accuracy of blood analyte measurement can increase. For example, in one embodiment, a convex bump of about 1 mm to about 3 mm in height and about 10 mm<sup>2</sup> to about 60 mm<sup>2</sup> was found to help signal strength by about an order of magnitude versus other shapes. Of course other dimensions and sizes can be employed in other embodiments. Depending on the properties desired, the length, width, and height of the protrusion 305 can be selected. In making such determinations, consideration can be made of protrusion's 305 effect on blood flow at the measurement site and mean path length for optical radiation passing through openings 320, 321, 322, and 323. Patient comfort can also be considered in determining the size and shape of the protrusion.

In an embodiment, the protrusion 305 can include a pliant material, including soft plastic or rubber, which can somewhat conform to the shape of a measurement site. Pliant materials can improve patient comfort and tactility by conforming the measurement site contact area 370 to the measurement site. Additionally, pliant materials can minimize or reduce noise, such as ambient light. Alternatively, the protrusion 305 can be made from a rigid material, such as hard plastic or metal.

Rigid materials can improve measurement accuracy of a blood analyte by conforming the measurement site to the contact area 370. The contact area 370 can be an ideal shape for improving accuracy or reducing noise. Selecting a material for the protrusion 305 can include consideration of materials that do not significantly alter blood flow at the measurement site. The protrusion 305 and the contact area 370 can include a combination of materials with various characteristics.

The contact area 370 serves as a contact surface for the measurement site. For example, in some embodiments, the contact area 370 can be shaped for contact with a patient's finger. Accordingly, the contact area 370 can be sized and shaped for different sizes of fingers. The contact area 370 can be constructed of different materials for reflective purposes as well as for the comfort of the patient. For example,

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the contact area 370 can be constructed from materials having various hardness and textures, such as plastic, gel, foam, and the like.

The formulas and analysis that follow with respect to FIG. 5 provide insight into how selecting these variables can alter 5 transmittance and intensity gain of optical radiation that has been applied to the measurement site. These examples do not limit the scope of this disclosure.

Referring to FIG. 5, a plot 500 is shown that illustrates examples of effects of embodiments of the protrusion 305 on 10 the SNR at various wavelengths of light. As described above, the protrusion 305 can assist in conforming the tissue and effectively reduce its mean path length. In some instances, this effect by the protrusion 305 can have significant impact on increasing the SNR.

According to the Beer Lambert law, a transmittance of light (I) can be expressed as follows:  $I=I_o*e^{-m^*b^*c}$ , where  $I_o$  is the initial power of light being transmitted, m is the path length traveled by the light, and the component "b\*c" corresponds to the bulk absorption of the light at a specific 20 wavelength of light. For light at about 1600 nm to about 1700 nm, for example, the bulk absorption component is generally around 0.7 mm<sup>-1</sup>. Assuming a typical finger thickness of about 12 mm and a mean path length of 20 mm due to tissue scattering, then  $I=I_o*e^{(-20^*0.7)}$ .

In an embodiment where the protrusion 305 is a convex bump, the thickness of the finger can be reduced to 10 mm (from 12 mm) for some fingers and the effective light mean path is reduced to about 16.6 mm from 20 mm (see box 510). This results in a new transmittance,  $I_1 = I_0 * e^{(-16.6*0.7)}$ . A 30 curve for a typical finger (having a mean path length of 20 mm) across various wavelengths is shown in the plot 500 of FIG. 5. The plot 500 illustrates potential effects of the protrusion 305 on the transmittance. As illustrated, comparing I and I<sub>1</sub> results in an intensity gain of  $e^{(-16.6*0.7)}/e^{(-20*0.7)}$ , 35 which is about a 10 times increase for light in the about 1600 nm to about 1700 nm range. Such an increase can affect the SNR at which the sensor can operate. The foregoing gains can be due at least in part to the about 1600 nm to about 1700 nm range having high values in bulk absorptions (water, 40 protein, and the like), e.g., about 0.7 mm<sup>-1</sup>. The plot 500 also shows improvements in the visible/near-infrared range (about 600 nm to about 1300 nm).

Turning again to FIGS. 3A through 3C, an example heat sink 350a is also shown. The heat sink 350a can be attached 45 to, or protrude from an outer surface of, the sensor 301a, thereby providing increased ability for various sensor components to dissipate excess heat. By being on the outer surface of the sensor 301a in certain embodiments, the heat sink 350a can be exposed to the air and thereby facilitate 50 more efficient cooling. In an embodiment, one or more of the emitters (see FIG. 1) generate sufficient heat that inclusion of the heat sink 350a can advantageously allows the sensor 301a to remain safely cooled. The heat sink 350a can include one or more materials that help dissipate heat, such 55 as, for example, aluminum, steel, copper, carbon, combinations of the same, or the like. For example, in some embodiments, the emitter shell 304a can include a heat conducting material that is also readily and relatively inexpensively moldable into desired shapes and forms.

In some embodiments, the heat sink 350a includes metalicized plastic. The metalicized plastic can include aluminum and carbon, for example. The material can allow for improved thermal conductivity and diffusivity, which can increase commercial viability of the heat sink. In some 65 embodiments, the material selected to construct the heat sink 350a can include a thermally conductive liquid crystalline

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polymer, such as CoolPoly® D5506, commercially available from Cool Polymers®, Inc. of Warwick, R.I. Such a material can be selected for its electrically non-conductive and dielectric properties so as, for example, to aid in electrical shielding. In an embodiment, the heat sink 350a provides improved heat transfer properties when the sensor 301a is active for short intervals of less than a full day's use. In an embodiment, the heat sink 350a can advantageously provide improved heat transfers in about three (3) to about four (4) minute intervals, for example, although a heat sink 350a can be selected that performs effectively in shorter or longer intervals.

Moreover, the heat sink 350a can have different shapes and configurations for aesthetic as well as for functional purposes. In an embodiment, the heat sink is configured to maximize heat dissipation, for example, by maximizing surface area. In an embodiment, the heat sink 350a is molded into a generally curved surface and includes one or more fins, undulations, grooves, or channels. The example heat sink 350a shown includes fins 351a (see FIG. 3A).

An alternative shape of a sensor 301b and heat sink 350b is shown in FIG. 3D. The sensor 301b can include some or all of the features of the sensor 301a. For example, the sensor 301b includes an enclosure 302b formed by an emitter shell 304b and a detector shell 306b, pivotably connected about a pivot 303a. The emitter shell 304b can also include absorbing opaque material on one or more flaps 307b, and the detector shell 306a can also include absorbing opaque material at various areas, such as lower area 308b.

However, the shape of the sensor 301b is different in this embodiment. In particular, the heat sink 350b includes comb protrusions 351b. The comb protrusions 351b are exposed to the air in a similar manner to the fins 351a of the heat sink 350a, thereby facilitating efficient cooling of the sensor 301b.

FIG. 3E illustrates a more detailed example of a detector shell 306b of the sensor 301b. The features described with respect to the detector shell 306b can also be used with the detector shell 306a of the sensor 301a.

As shown, the detector shell 306b includes detectors 316. The detectors 316 can have a predetermined spacing 340 from each other, or a spatial relationship among one another that results in a spatial configuration. This spatial configuration can purposefully create a variation of path lengths among detectors 316 and the emitter discussed above.

In the depicted embodiment, the detector shell 316 can hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays can also be useful to detect light piping (e.g., light that bypasses measurement site 102). In the detector shell 316, walls can be provided to separate the individual photodiode arrays to prevent or reduce mixing of light signals from distinct quadrants. In addition, the detector shell 316 can be covered by windows of transparent material, such as glass, plastic, or the like, to allow maximum or increased transmission of power light captured. In various embodiments, the transparent materials used can also be partially transparent or translucent or can otherwise pass some or all of the optical radiation passing through 60 them. As noted, this window can include some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

As further illustrated by FIG. 3E, the detectors 316 can have a spatial configuration of a grid. However, the detectors 316 can be arranged in other configurations that vary the path length. For example, the detectors 316 can be arranged in a linear array, a logarithmic array, a two-dimensional

array, a zig-zag pattern, or the like. Furthermore, any number of the detectors 316 can be employed in certain embodi-

FIG. 3F illustrates another embodiment of a sensor 301f. The sensor 301f can include some or all of the features of the 5 sensor 301a of FIG. 3A described above. For example, the sensor 301f includes an enclosure 302f formed by an upper section or emitter shell 304f, which is pivotably connected with a lower section or detector shell 306f around a pivot point 303f. The emitter shell 304f can also include absorbing opaque material on various areas, such as on one or more flaps 307f, to reduce ambient light entering the sensor 301f. The detector shell 306f can also include absorbing opaque material at various areas, such as a lower area 308f. The sensor 301f also includes a heat sink 350f, which includes 15 fins 351f.

In addition to these features, the sensor 301f includes a flex circuit cover 360, which can be made of plastic or another suitable material. The flex circuit cover 360 can cover and thereby protect a flex circuit (not shown) that 20 extends from the emitter shell 304f to the detector shell 306f. An example of such a flex circuit is illustrated in U.S. Publication No. 2006/0211924, incorporated above (see FIG. 46 and associated description, which is hereby specifically incorporated by reference). The flex circuit cover 360 25 is shown in more detail below in FIG. 17.

In addition, sensors 301a-f has extra length—extends to second joint on finger-Easier to place, harder to move due to cable, better for light piping.

FIGS. 4A through 4C illustrate example arrangements of 30 a protrusion 405, which is an embodiment of the protrusion 305 described above. In an embodiment, the protrusion 405 can include a measurement site contact area 470. The measurement site contact area 470 can include a surface that into a flat or relatively flat surface.

The protrusion 405 can have dimensions that are suitable for a measurement site such as a patient's finger. As shown, the protrusion 405 can have a length 400, a width 410, and a height 430. The length 400 can be from about 9 to about 40 11 millimeters, e.g., about 10 millimeters. The width 410 can be from about 7 to about 9 millimeters, e.g., about 8 millimeters. The height 430 can be from about 0.5 millimeters to about 3 millimeters, e.g., about 2 millimeters. In an embodiment, the dimensions 400, 410, and 430 can be 45 selected such that the measurement site contact area 470 includes an area of about 80 square millimeters, although larger and smaller areas can be used for different sized tissue for an adult, an adolescent, or infant, or for other considerations.

The measurement site contact area 470 can also include differently shaped surfaces that conform the measurement site into different shapes. For example, the measurement site contact area 470 can be generally curved and/or convex with respect to the measurement site. The measurement site 55 contact area 470 can be other shapes that reduce or even minimize air between the protrusion 405 and/or the measurement site. Additionally, the surface pattern of the measurement site contact area 470 can vary from smooth to bumpy, e.g., to provide varying levels of grip.

In FIGS. 4A and 4C, openings or windows 420, 421, 422, and 423 can include a wide variety of shapes and sizes, including for example, generally square, circular, triangular, or combinations thereof. The windows 420, 421, 422, and 423 can be of non-uniform shapes and sizes. As shown, the 65 windows 420, 421, 422, and 423 can be evenly spaced out in a grid like arrangement. Other arrangements or patterns of

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arranging the windows 420, 421, 422, and 423 are possible. For example, the windows 420, 421, 422, and 423 can be placed in a triangular, circular, or linear arrangement. In some embodiments, the windows 420, 421, 422, and 423 can be placed at different heights with respect to the finger bed 310 of FIG. 3. The windows 420, 421, 422, and 423 can also mimic or approximately mimic a configuration of, or even house, a plurality of detectors.

FIGS. 6A through 6D illustrate another embodiment of a protrusion 605 that can be used as the tissue shaper 105 described above or in place of the protrusions 305, 405 described above. The depicted protrusion 605 is a partially cylindrical lens having a partial cylinder 608 and an extension 610. The partial cylinder 608 can be a half cylinder in some embodiments; however, a smaller or greater portion than half of a cylinder can be used. Advantageously, in certain embodiments, the partially cylindrical protrusion 605 focuses light onto a smaller area, such that fewer detectors can be used to detect the light attenuated by a measurement

FIG. 6A illustrates a perspective view of the partially cylindrical protrusion 605. FIG. 6B illustrates a front elevation view of the partially cylindrical protrusion 605. FIG. 6C illustrates a side view of the partially cylindrical protrusion 605. FIG. 6D illustrates a top view of the partially cylindrical protrusion 605.

Advantageously, in certain embodiments, placing the partially cylindrical protrusion 605 over the photodiodes in any of the sensors described above adds multiple benefits to any of the sensors described above. In one embodiment, the partially cylindrical protrusion 605 penetrates into the tissue and reduces the path length of the light traveling in the tissue, similar to the protrusions described above.

The partially cylindrical protrusion 605 can also collect molds body tissue of a measurement site, such as a finger, 35 light from a large surface and focus down the light to a smaller area. As a result, in certain embodiments, signal strength per area of the photodiode can be increased. The partially cylindrical protrusion 605 can therefore facilitate a lower cost sensor because, in certain embodiments, less photodiode area can be used to obtain the same signal strength. Less photodiode area can be realized by using smaller photodiodes or fewer photodiodes (see, e.g., FIG. 14). If fewer or smaller photodiodes are used, the partially cylindrical protrusion 605 can also facilitate an improved SNR of the sensor because fewer or smaller photodiodes can have less dark current.

> The dimensions of the partially cylindrical protrusion 605 can vary based on, for instance, a number of photodiodes used with the sensor. Referring to FIG. 6C, the overall height of the partially cylindrical protrusion 605 (measurement "a") in some implementations is about 1 to about 3 mm. A height in this range can allow the partially cylindrical protrusion 605 to penetrate into the pad of the finger or other tissue and reduce the distance that light travels through the tissue. Other heights, however, of the partially cylindrical protrusion 605 can also accomplish this objective. For example, the chosen height of the partially cylindrical protrusion 605 can be selected based on the size of the measurement site, whether the patient is an adult or child, and so on. In an embodiment, the height of the protrusion 605 is chosen to provide as much tissue thickness reduction as possible while reducing or preventing occlusion of blood vessels in the

> Referring to FIG. 6D, the width of the partially cylindrical protrusion 605 (measurement "b") can be about 3 to about 5 mm. In one embodiment, the width is about 4 mm. In one embodiment, a width in this range provides good penetration

of the partially cylindrical protrusion **605** into the tissue to reduce the path length of the light. Other widths, however, of the partially cylindrical protrusion **605** can also accomplish this objective. For example, the width of the partially cylindrical protrusion **605** can vary based on the size of the measurement site, whether the patient is an adult or child, and so on. In addition, the length of the protrusion **605** could be about 10 mm, or about 8 mm to about 12 mm, or smaller than 8 mm or greater than 12 mm.

In certain embodiments, the focal length (f) for the partially cylindrical protrusion 605 can be expressed as:

$$f = \frac{R}{n-1}$$

where R is the radius of curvature of the partial cylinder **608** and n is the index of refraction of the material used. In certain embodiments, the radius of curvature can be between 20 about 1.5 mm and about 2 mm. In another embodiment, the partially cylindrical protrusion **605** can include a material, such as nBK7 glass, with an index of refraction of around 1.5 at 1300 nm, which can provide focal lengths of between about 3 mm and about 4 mm.

A partially cylindrical protrusion 605 having a material with a higher index of refraction such as nSF11 glass (e.g., n=1.75 at 1300 nm) can provide a shorter focal length and possibly a smaller photodiode chip, but can also cause higher reflections due to the index of refraction mismatch with air. Many types of glass or plastic can be used with index of refraction values ranging from, for example, about 1.4 to about 1.9. The index of refraction of the material of the protrusion 605 can be chosen to improve or optimize the light focusing properties of the protrusion 605. A plastic partially cylindrical protrusion 605 could provide the cheapest option in high volumes but can also have some undesired light absorption peaks at wavelengths higher than 1500 nm. Other focal lengths and materials having different indices of refraction can be used for the partially cylindrical protrusion 40 605.

Placing a photodiode at a given distance below the partially cylindrical protrusion 605 can facilitate capturing some or all of the light traveling perpendicular to the lens within the active area of the photodiode (see FIG. 14). 45 Different sizes of the partially cylindrical protrusion 605 can use different sizes of photodiodes. The extension 610 added onto the bottom of the partial cylinder 608 is used in certain embodiments to increase the height of the partially cylindrical protrusion 605. In an embodiment, the added height is 50 such that the photodiodes are at or are approximately at the focal length of the partially cylindrical protrusion 605. In an embodiment, the added height provides for greater thinning of the measurement site. In an embodiment, the added height assists in deflecting light piped through the sensor. This is 55 because light piped around the sensor passes through the side walls of the added height without being directed toward the detectors. The extension 610 can also further facilitate the protrusion 605 increasing or maximizing the amount of light that is provided to the detectors. In some embodiments, 60 the extension 610 can be omitted.

FIG. 6E illustrates another view of the sensor 301 f of FIG. 3F, which includes an embodiment of a partially cylindrical protrusion 605b. Like the sensor 301A shown in FIGS. 3B and 3C, the sensor 301f includes a finger bed 310f. The 65 finger bed 310f includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger

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bed 310f also includes the ridges or channels 314 described above with respect to FIGS. 3B and 3C.

The example of finger bed 310f shown also includes the protrusion 605b, which includes the features of the protrusion 605 described above. In addition, the protrusion 605b also includes chamfered edges 607 on each end to provide a more comfortable surface for a finger to slide across (see also FIG. 14D). In another embodiment, the protrusion 605b could instead include a single chamfered edge 607 proximal to the ridges 314. In another embodiment, one or both of the chamfered edges 607 could be rounded.

The protrusion **605***b* also includes a measurement site contact area **670** that can contact body tissue of a measurement site. The protrusion **605***b* can be removed from or integrated with the finger bed **310***f*. Interchangeable, differently shaped protrusions **605***b* can also be provided, which can correspond to different finger shapes, characteristics, opacity, sizes, or the like.

FIGS. 7A and 7B illustrate block diagrams of sensors 701
that include example arrangements of conductive glass or
conductive coated glass for shielding. Advantageously, in
certain embodiments, the shielding can provide increased
SNR. The features of the sensors 701 can be implemented
with any of the sensors 101, 201, 301 described above.

Although not shown, the partially cylindrical protrusion 605
of FIG. 6 can also be used with the sensors 701 in certain
embodiments.

For example, referring specifically to FIG. 7A, the sensor 701a includes an emitter housing 704a and a detector housing 706. The emitter housing 704a includes LEDs 104. The detector housing 706a includes a tissue bed 710a with an opening or window 703a, the conductive glass 730a, and one or more photodiodes for detectors 106 provided on a submount 707a.

During operation, a finger 102 can be placed on the tissue bed 710a and optical radiation can be emitted from the LEDs 104. Light can then be attenuated as it passes through or is reflected from the tissue of the finger 102. The attenuated light can then pass through the opening 703a in the tissue bed 710a. Based on the received light, the detectors 106 can provide a detector signal 107, for example, to the front end interface 108 (see FIG. 1).

In the depicted embodiment, the conductive glass 730 is provided in the opening 703. The conductive glass 730 can thus not only permit light from the finger to pass to the detectors 106, but it can also supplement the shielding of the detectors 106 from noise. The conductive glass 730 can include a stack or set of layers. In FIG. 7A, the conductive glass 730a is shown having a glass layer 731 proximate the finger 102 and a conductive layer 733 electrically coupled to the shielding 790a.

In an embodiment, the conductive glass 730a can be coated with a conductive, transparent or partially transparent material, such as a thin film of indium tin oxide (ITO). To supplement electrical shielding effects of a shielding enclosure 790a, the conductive glass 730a can be electrically coupled to the shielding enclosure 790a. The conductive glass 730a can be electrically coupled to the shielding 704a based on direct contact or via other connection devices, such as a wire or another component.

The shielding enclosure **790***a* can be provided to encompass the detectors **106** to reduce or prevent noise. For example, the shielding enclosure **790***a* can be constructed from a conductive material, such as copper, in the form of a metal cage. The shielding or enclosure a can include an opaque material to not only reduce electrical noise, but also ambient optical noise.

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In some embodiments, the shielding enclosure 790a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. 5 Furthermore, the shielding enclosure 790a can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108

Referring to FIG. 7B, another block diagram of an 10 example sensor 701b is shown. A tissue bed 710b of the sensor 701b includes a protrusion 705b, which is in the form of a convex bump. The protrusion 705b can include all of the features of the protrusions or tissue shaping materials described above. For example, the protrusion 705b includes 15 a contact area 370 that comes in contact with the finger 102 and which can include one or more openings 703b. One or more components of conductive glass 730b can be provided in the openings 703. For example, in an embodiment, each of the openings 703 can include a separate window of the 20 conductive glass 730b. In an embodiment, a single piece of the conductive glass 730b can used for some or all of the openings 703b. The conductive glass 730b is smaller than the conductive glass 730a in this particular embodiment.

A shielding enclosure 790b is also provided, which can 25 have all the features of the shielding enclosure 790a. The shielding enclosure 790b is smaller than the shielding enclosure 790a; however, a variety of sizes can be selected for the shielding enclosures 790.

In some embodiments, the shielding enclosure **790***b* can 30 be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding enclosure **790***b* can also be used 35 to house various other components, such as sigma delta components for various embodiments of front end interfaces **108** 

FIGS. 8A through 8D illustrate a perspective view, side views, and a bottom elevation view of the conductive glass 40 described above with respect to the sensors 701a, 701b. As shown in the perspective view of FIG. 8A and side view of FIG. 8B, the conductive glass 730 includes the electrically conductive material 733 described above as a coating on the glass layer 731 described above to form a stack. In an 45 embodiment where the electrically conductive material 733 includes indium tin oxide, surface resistivity of the electrically conductive material 733 can range approximately from 30 ohms per square inch to 500 ohms per square inch, or approximately 30, 200, or 500 ohms per square inch. As 50 would be understood by a person of skill in the art from the present disclosure, other resistivities can also be used which are less than 30 ohms or more than 500 ohms. Other transparent, electrically conductive materials can be used as the material 733.

Although the conductive material 733 is shown spread over the surface of the glass layer 731, the conductive material 733 can be patterned or provided on selected portions of the glass layer 731. Furthermore, the conductive material 733 can have uniform or varying thickness depending on a desired transmission of light, a desired shielding effect, and other considerations.

In FIG. 8C, a side view of a conductive glass 830a is shown to illustrate an embodiment where the electrically conductive material 733 is provided as an internal layer 65 between two glass layers 731, 835. Various combinations of integrating electrically conductive material 733 with glass

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are possible. For example, the electrically conductive material 733 can be a layer within a stack of layers. This stack of layers can include one or more layers of glass 731, 835, as well as one or more layers of conductive material 733. The stack can include other layers of materials to achieve desired characteristics.

In FIG. 8D, a bottom perspective view is shown to illustrate an embodiment where a conductive glass 830b can include conductive material 837 that occupies or covers a portion of a glass layer 839. This embodiment can be useful, for example, to create individual, shielded windows for detectors 106, such as those shown in FIG. 3C. The conductive material 837 can be patterned to include an area 838 to allow light to pass to detectors 106 and one or more strips 841 to couple to the shielding 704 of FIG. 7.

Other configurations and patterns for the conductive material can be used in certain embodiments, such as, for example, a conductive coating lining periphery edges, a conductive coating outlaid in a pattern including a grid or other pattern, a speckled conductive coating, coating outlaid in lines in either direction or diagonally, varied thicknesses from the center out or from the periphery in, or other suitable patterns or coatings that balance the shielding properties with transparency considerations.

FIG. 9 depicts an example graph 900 that illustrates comparative results obtained by an example sensor having components similar to those disclosed above with respect to FIGS. 7 and 8. The graph 900 depicts the results of the percentage of transmission of varying wavelengths of light for different types of windows used in the sensors described above.

A line 915 on the graph 900 illustrates example light transmission of a window made from plain glass. As shown, the light transmission percentage of varying wavelengths of light is approximately 90% for a window made from plain glass. A line 920 on the graph 900 demonstrates an example light transmission percentage for an embodiment in which a window is made from glass having an ITO coating with a surface resistivity of 500 ohms per square inch. A line 925 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 200 ohms per square inch. A line 930 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 30 ohms per square inch.

The light transmission percentage for a window with currently available embedded wiring can have a light trans50 mission percentage of approximately 70%. This lower percentage of light transmission can be due to the opacity of the wiring employed in a currently available window with wiring. Accordingly, certain embodiments of glass coatings described herein can employ, for example, ITO coatings with different surface resistivity depending on the desired light transmission, wavelengths of light used for measurement, desired shielding effect, and other criteria.

FIGS. 10A through 10B illustrate comparative noise floors of example implementations of the sensors described above. Noise can include optical noise from ambient light and electro-magnetic noise, for example, from surrounding electrical equipment. In FIG. 10A, a graph 1000 depicts possible noise floors for different frequencies of noise for an embodiment in which one of the sensors described above included separate windows for four (4) detectors 106. One or more of the windows included an embedded grid of wiring as a noise shield. Symbols 1030-1033 illustrate the

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noise floor performance for this embodiment. As can be seen, the noise floor performance can vary for each of the openings and based on the frequency of the noise.

In FIG. 10B, a graph 1050 depicts a noise floor for frequencies of noise 1070 for an embodiment in which the sensor included separate openings for four (4) detectors 106 and one or more windows that include an ITO coating. In this embodiment, a surface resistivity of the ITO used was about 500 ohms per square inch. Symbols 1080-1083 illustrate the noise floor performance for this embodiment. As can be seen, the noise floor performance for this embodiment can vary less for each of the openings and provide lower noise floors in comparison to the embodiment of FIG.  $10\,$ 

FIG. 11A illustrates an example structure for configuring the set of optical sources of the emitters described above. As shown, an emitter 104 can include a driver 1105, a thermistor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, 25 other thermistors can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such a temperature can also be helpful in correcting for wavelength drift due to changes in water absorption, which can be 30 temperature dependent, thereby providing more accurate data useful in detecting blood analytes like glucose. In addition, using a thermistor or other type of temperature sensitive device may be useful for detecting extreme temperatures at the measurement site that are too hot or too cold. 35 The presence of low perfusion may also be detected, for example, when the finger of a patient has become too cold. Moreover, shifts in temperature at the measurement site can alter the absorption spectrum of water and other tissue in the measurement cite. A thermistor's temperature reading can be 40 used to adjust for the variations in absorption spectrum changes in the measurement site.

The driver 1105 can provide pulses of current to the emitter 1104. In an embodiment, the driver 1105 drives the emitter 1104 in a progressive fashion, for example, in an 45 alternating manner based on a control signal from, for example, a processor (e.g., the processor 110). For example, the driver 1105 can drive the emitter 1104 with a series of pulses to about 1 milliwatt (mW) for visible light to light at about 1300 nm and from about 40 mW to about 100 mW for 50 light at about 1600 nm to about 1700 nm. However, a wide number of driving powers and driving methodologies can be used. The driver 1105 can be synchronized with other parts of the sensor and can minimize or reduce any jitter in the timing of pulses of optical radiation emitted from the emitter 55 1104. In some embodiments, the driver 1105 is capable of driving the emitter 1104 to emit an optical radiation in a pattern that varies by less than about 10 parts-per-million; however other amounts of variation can be used.

The submount 1106 provides a support structure in certain 60 embodiments for aligning the top-emitting LEDs 1102 and the side-emitting LEDs 1104 so that their optical radiation is transmitted generally towards the measurement site. In some embodiments, the submount 1106 is also constructed of aluminum nitride (AlN) or beryllium oxide (BEO) for heat 65 dissipation, although other materials or combinations of materials suitable for the submount 1106 can be used.

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FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring a blood constituent or analyte like glucose. In some embodiments, emitter 104 may be driven in a progressive fashion to minimize noise and increase SNR of sensor 101. For example, emitter 104 may be driven based on a progression of power/current delivered to LEDs 1102 and 1104.

In some embodiments, emitter 104 may be configured to emit pulses centered about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about 1665 nm. In another embodiment, the emitter 104 may emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of course, emitter 104 may be configured to transmit any of a variety of wavelengths of visible, or near-infrared optical radiation.

istor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, other thermistors can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such

For example, as shown in FIG. 11B, the sequence of optical radiation pulses are shown having a logarithmic-like progression in power/current. In some embodiments, the timing of these pulses is based on a cycle of about 400 slots running at 48 kHz (e.g. each time slot may be approximately 0.02 ms or 20 microseconds). An artisan will recognize that term "slots" includes its ordinary meaning, which includes a time period that may also be expressed in terms of a frequency. In the example shown, pulses from top emitting LEDs 1102 may have a pulse width of about 40 time slots (e.g., about 0.8 ms) and an off period of about 4 time slots in between. In addition, pulses from side emitting LEDs 1104 (e.g., or a laser diode) may have a pulse width of about 60 time slots (e.g., about 1.25 ms) and a similar off period of about 4 time slots. A pause of about 70 time slots (e.g. 1.5 ms) may also be provided in order to allow driver circuit 1105 to stabilize after operating at higher current/power.

As shown in FIG. 11B, top emitting LEDs 1102 may be initially driven with a power to approximately 1 mW at a current of about 20-100 mA. Power in these LEDs may also be modulated by using a filter or covering of black dye to reduce power output of LEDs. In this example, top emitting LEDs 1102 may be driven at approximately 0.02 to 0.08 mW. The sequence of the wavelengths may be based on the current requirements of top emitting LEDs 502 for that particular wavelength. Of course, in other embodiments, different wavelengths and sequences of wavelengths may be output from emitter 104.

Subsequently, side emitting LEDs 1104 may be driven at higher powers, such as about 40-100 mW and higher currents of about 600-800 mA. This higher power may be employed in order to compensate for the higher opacity of tissue and water in measurement site 102 to these wavelengths. For example, as shown, pulses at about 1630 nm, about 1660 nm, and about 1615 nm may be output with progressively higher power, such as at about 40 mW, about 50 mW, and about 60 mW, respectively. In this embodiment, the order of wavelengths may be based on the optical characteristics of that wavelength in tissue as well as the

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current needed to drive side emitting LEDs 1104. For example, in this embodiment, the optical pulse at about 1615 nm is driven at the highest power due to its sensitivity in detecting analytes like glucose and the ability of light at this wavelength to penetrate tissue. Of course, different wavelengths and sequences of wavelengths may be output from emitter 104.

As noted, this progression may be useful in some embodiments because it allows the circuitry of driver circuit 1105 to stabilize its power delivery to LEDs 1102 and 1104. 10 Driver circuit 1105 may be allowed to stabilize based on the duty cycle of the pulses or, for example, by configuring a variable waiting period to allow for stabilization of driver circuit 1105. Of course, other variations in power/current and wavelength may also be employed in the present disclosure.

Modulation in the duty cycle of the individual pulses may also be useful because duty cycle can affect the signal noise ratio of the system 100. That is, as the duty cycle is increased so may the signal to noise ratio.

Furthermore, as noted above, driver circuit 1105 may monitor temperatures of the LEDs 1102 and 1104 using the thermistor 1120 and adjust the output of LEDs 1102 and 1104 accordingly. Such a temperature may be to help sensor 101 correct for wavelength drift due to changes in water 25 absorption, which can be temperature dependent.

FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. As shown, the emitter 104 can include components mounted on a substrate 1108 and on submount 30 1106. In particular, top-emitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108. Side emitting LEDS 1104 may be mounted on submount 1106. As noted, side-emitting LEDs 1104 may be included in emitter 104 for emitting near infrared light.

As also shown, the sensor of FIG. 11C may include a thermistor 1120. As noted, the thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to 40 heating. In addition, other thermistors (not shown) can be employed, for example, to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby 45 providing more accurate data useful in detecting blood analytes like glucose.

In some embodiments, the emitter 104 may be implemented without the use of side emitting LEDs. For example, certain blood constituents, such as total hemoglobin, can be 50 measured by embodiments of the disclosure without the use of side emitting LEDs. FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. In particular, an emitter 104 that is configured for a blood constituent, such as total 55 hemoglobin, is shown. The emitter 104 can include components mounted on a substrate 1108. In particular, topemitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108.

As also shown, the emitter of FIG. 11D may include a 60 thermistor 1120. The thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 due to heating.

FIG. 12A illustrates a detector submount 1200 having 65 photodiode detectors that are arranged in a grid pattern on the detector submount 1200 to capture light at different

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quadrants from a measurement site. One detector submount 1200 can be placed under each window of the sensors described above, or multiple windows can be placed over a single detector submount 1200. The detector submount 1200 can also be used with the partially cylindrical protrusion 605 described above with respect to FIG. 6.

The detectors include photodiode detectors 1-4 that are arranged in a grid pattern on the submount **1200** to capture light at different quadrants from the measurement site. As noted, other patterns of photodiodes, such as a linear row, or logarithmic row, can also be employed in certain embodiments

As shown, the detectors 1-4 may have a predetermined spacing from each other, or spatial relationship among one another that result in a spatial configuration. This spatial configuration can be configured to purposefully create a variation of path lengths among detectors 106 and the point light source discussed above.

Detectors may hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays may also be useful to detect light piping (i.e., light that bypasses measurement site 102). As shown, walls may separate the individual photodiode arrays to prevent mixing of light signals from distinct quadrants. In addition, as noted, the detectors may be covered by windows of transparent material, such as glass, plastic, etc., to allow maximum transmission of power light captured. As noted, this window may comprise some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

FIGS. 12B through 12D illustrate a simplified view of exemplary arrangements and spatial configurations of photodiodes for detectors 106. As shown, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a grid pattern on detector submount 1200 to capture light at different quadrants from measurement site 102.

As noted, other patterns of photodiodes may also be employed in embodiments of the present disclosure, including, for example, stacked or other configurations recognizable to an artisan from the disclosure herein. For example, detectors 106 may be arranged in a linear array, a logarithmic array, a two-dimensional array, and the like. Furthermore, an artisan will recognize from the disclosure herein that any number of detectors 106 may be employed by embodiments of the present disclosure.

For example, as shown in FIG. 12B, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a substantially linear configuration on submount 1200. In this embodiment shown, photodiode detectors 1-4 are substantially equally spaced apart (e.g., where the distance D is substantially the same between detectors 1-4).

In FIG. 12C, photodiode detectors 1-4 may be arranged in a substantially linear configuration on submount 1200, but may employ a substantially progressive, substantially logarithmic, or substantially semi-logarithmic spacing (e.g., where distances D1>D2>D3). This arrangement or pattern may be useful for use on a patient's finger and where the thickness of the finger gradually increases.

In FIG. 12D, a different substantially grid pattern on submount 1200 of photodiode detectors 1-4 is shown. As noted, other patterns of detectors may also be employed in embodiments of the present invention.

FIGS. 12E through 12H illustrate several embodiments of photodiodes that may be used in detectors 106. As shown in these figures, a photodiode 1202 of detector 106 may comprise a plurality of active areas 1204. These active areas

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204 may be coupled together via a common cathode 1206 or anode 1208 in order to provide a larger effective detection area.

In particular, as shown in FIG. 12E, photodiode 1202 may comprise two (2) active areas 1204a and 1204b. In FIG. 12F, 5 photodiode 1202 may comprise four (4) active areas 1204c-f. In FIG. 12G, photodiode 1202 may comprise three (3) active areas 1204g-i. In FIG. 12H, photodiode 1202 may comprise nine (9) active areas 1204j-r. The use of smaller active areas may be useful because smaller active areas can 10 be easier to fabricate and can be fabricated with higher purity. However, one skilled in the art will recognize that various sizes of active areas may be employed in the photodiode 1202.

FIG. 13 illustrates an example multi-stream process 1300. 15 The multi-stream process 1300 can be implemented by the data collection system 100 and/or by any of the sensors described above. As shown, a control signal from a signal processor 1310 controls a driver 1305. In response, an emitter 1304 generates a pulse sequence 1303 from its 20 emitter (e.g., its LEDs) into a measurement site or sites 1302. As described above, in some embodiments, the pulse sequence 1303 is controlled to have a variation of about 10 parts per million or less. Of course, depending on the analyte desired, the tolerated variation in the pulse sequence 1303 25 can be greater (or smaller).

In response to the pulse sequence 1300, detectors 1 to n (n being an integer) in a detector 1306 capture optical radiation from the measurement site 1302 and provide respective streams of output signals. Each signal from one of 30 detectors 1-n can be considered a stream having respective time slots corresponding to the optical pulses from emitter sets 1-n in the emitter 1304. Although n emitters and n detectors are shown, the number of emitters and detectors need not be the same in certain implementations.

A front end interface 1308 can accept these multiple streams from detectors 1-n and deliver one or more signals or composite signal(s) back to the signal processor 1310. A stream from the detectors 1-n can thus include measured light intensities corresponding to the light pulses emitted 40 from the emitter 1304.

The signal processor 1310 can then perform various calculations to measure the amount of glucose and other analytes based on these multiple streams of signals. In order to help explain how the signal processor 1310 can measure 45 analytes like glucose, a primer on the spectroscopy employed in these embodiments will now be provided.

Spectroscopy is premised upon the Beer-Lambert law. According to this law, the properties of a material, e.g., glucose present in a measurement site, can be deterministically calculated from the absorption of light traveling through the material. Specifically, there is a logarithmic relation between the transmission of light through a material and the concentration of a substance and also between the transmission and the length of the path traveled by the light. 55 As noted, this relation is known as the Beer-Lambert law.

The Beer-Lambert law is usually written as:

Absorbance A=m\*b\*c, where:

m is the wavelength-dependent molar absorptivity coefficient (usually expressed in units of M<sup>-1</sup> cm<sup>-1</sup>):

b is the mean path length; and

c is the analyte concentration (e.g., the desired parameter). In spectroscopy, instruments attempt to obtain the analyte concentration (c) by relating absorbance (A) to transmittance (T). Transmittance is a proportional value defined as:

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I is the light intensity measured by the instrument from the measurement site; and

I<sub>0</sub> is the initial light intensity from the emitter.

Absorbance (A) can be equated to the transmittance (T) by the equation:

 $A=-\log T$ 

Therefore, substituting equations from above:

 $A = -\log(I/I_o)$ 

In view of this relationship, spectroscopy thus relies on a proportional-based calculation of  $-\log(I/I_o)$  and solving for analyte concentration (c).

Typically, in order to simplify the calculations, spectroscopy will use detectors that are at the same location in order to keep the path length (b) a fixed, known constant. In addition, spectroscopy will employ various mechanisms to definitively know the transmission power (I<sub>o</sub>), such as a photodiode located at the light source. This architecture can be viewed as a single channel or single stream sensor, because the detectors are at a single location.

However, this scheme can encounter several difficulties in measuring analytes, such as glucose. This can be due to the high overlap of absorption of light by water at the wavelengths relevant to glucose as well as other factors, such as high self-noise of the components.

Embodiments of the present disclosure can employ a different approach that in part allows for the measurement of analytes like glucose. Some embodiments can employ a bulk, non-pulsatile measurement in order to confirm or validate a pulsatile measurement. In addition, both the non-pulsatile and pulsatile measurements can employ, among other things, the multi-stream operation described above in order to attain sufficient SNR. In particular, a single light source having multiple emitters can be used to transmit light to multiple detectors having a spatial configuration.

A single light source having multiple emitters can allow for a range of wavelengths of light to be used. For example, visible, infrared, and near infrared wavelengths can be employed. Varying powers of light intensity for different wavelengths can also be employed.

Secondly, the use of multiple-detectors in a spatial configuration allow for a bulk measurement to confirm or validate that the sensor is positioned correctly. This is because the multiple locations of the spatial configuration can provide, for example, topology information that indicates where the sensor has been positioned. Currently available sensors do not provide such information. For example, if the bulk measurement is within a predetermined range of values, then this can indicate that the sensor is positioned correctly in order to perform pulsatile measurements for analytes like glucose. If the bulk measurement is outside of a certain range or is an unexpected value, then this can indicate that the sensor should be adjusted, or that the pulsatile measurements can be processed differently to compensate, such as using a different calibration curve or adjusting a calibration curve. This feature and others allow the embodiments to achieve noise cancellation and noise reduction, which can be several times greater in magnitude that what is achievable by currently available technology.

In order to help illustrate aspects of the multi-stream measurement approach, the following example derivation is provided. Transmittance (T) can be expressed as:

 $T=e^{-m*b*}$ 

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In terms of light intensity, this equation can also be rewritten as:

$$I/I_{o} = e^{-m*b*c}$$

Or, at a detector, the measured light (I) can be expressed  $\,_{5}$  as:

$$I = I_o *e^{-m*b*c}$$

As noted, in the present disclosure, multiple detectors (1 to n) can be employed, which results in  $I_1 \ldots I_n$  streams of measurements. Assuming each of these detectors have their own path lengths,  $b_1 \ldots b_n$ , from the light source, the measured light intensities can be expressed as:

$$I_{n} = I_{o} * e^{-m * b_{n} * c}$$

The measured light intensities at any two different detectors can be referenced to each other. For example:

$$I_1/I_n = (I_o * e^{-mb_1c})/(I_o * e^{-mb_nc})$$

As can be seen, the terms, I<sub>o</sub>, cancel out and, based on exponent algebra, the equation can be rewritten as:

$$I_1/I_n = e^{-(b_1-b_n)c}$$

From this equation, the analyte concentration (c) can now be derived from bulk signals  $I_1 \ldots I_n$  and knowing the respective mean path lengths  $b_1$  and  $b_n$ . This scheme also 25 allows for the cancelling out of  $I_o$ , and thus, noise generated by the emitter 1304 can be cancelled out or reduced. In addition, since the scheme employs a mean path length difference, any changes in mean path length and topological variations from patient to patient are easily accounted. 30 Furthermore, this bulk-measurement scheme can be extended across multiple wavelengths. This flexibility and other features allow embodiments of the present disclosure to measure blood analytes like glucose.

For example, as noted, the non-pulsatile, bulk measurements can be combined with pulsatile measurements to more accurately measure analytes like glucose. In particular, the non-pulsatile, bulk measurement can be used to confirm or validate the amount of glucose, protein, etc. in the pulsatile measurements taken at the tissue at the measurement site(s) 40 1302. The pulsatile measurements can be used to measure the amount of glucose, hemoglobin, or the like that is present in the blood. Accordingly, these different measurements can be combined to thus determine analytes like blood glucose.

FIG. 14A illustrates an embodiment of a detector submount 1400a positioned beneath the partially cylindrical protrusion 605 of FIG. 6 (or alternatively, the protrusion 605b). The detector submount 1400a includes two rows 1408a of detectors 1410a. The partially cylindrical protrusion 605 can facilitate reducing the number and/or size of 50 detectors used in a sensor because the protrusion 605 can act as a lens that focuses light onto a smaller area.

To illustrate, in some sensors that do not include the partially cylindrical protrusion 605, sixteen detectors can be used, including four rows of four detectors each. Multiple 55 rows of detectors can be used to measure certain analytes, such as glucose or total hemoglobin, among others. Multiple rows of detectors can also be used to detect light piping (e.g., light that bypasses the measurement site). However, using more detectors in a sensor can add cost, complexity, and 60 noise to the sensor.

Applying the partially cylindrical protrusion **605** to such a sensor, however, could reduce the number of detectors or rows of detectors used while still receiving the substantially same amount of light, due to the focusing properties of the 65 protrusion **605** (see FIG. **14B**). This is the example situation illustrated in FIG. **14**—two rows **1408***a* of detectors **1410***a* 

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are used instead of four. Advantageously, in certain embodiments, the resulting sensor can be more cost effective, have less complexity, and have an improved SNR, due to fewer and/or smaller photodiodes.

In other embodiments, using the partially cylindrical protrusion 605 can allow the number of detector rows to be reduced to one or three rows of four detectors. The number of detectors in each row can also be reduced. Alternatively, the number of rows might not be reduced but the size of the detectors can be reduced. Many other configurations of detector rows and sizes can also be provided.

FIG. 14B depicts a front elevation view of the partially cylindrical protrusion 605 (or alternatively, the protrusion 605b) that illustrates how light from emitters (not shown) can be focused by the protrusion 605 onto detectors. The protrusion 605 is placed above a detector submount 1400b having one or more detectors 1410b disposed thereon. The submount 1400b can include any number of rows of detectors 1410, although one row is shown.

Light, represented by rays 1420, is emitted from the emitters onto the protrusion 605. These light rays 1420 can be attenuated by body tissue (not shown). When the light rays 1420 enter the protrusion 605, the protrusion 605 acts as a lens to refract the rays into rays 1422. This refraction is caused in certain embodiments by the partially cylindrical shape of the protrusion 605. The refraction causes the rays 1422 to be focused or substantially focused on the one or more detectors 1410b. Since the light is focused on a smaller area, a sensor including the protrusion 605 can include fewer detectors to capture the same amount of light compared with other sensors.

FIG. 14C illustrates another embodiment of a detector submount 1400c, which can be disposed under the protrusion 605b (or alternatively, the protrusion 605). The detector submount 1400c includes a single row 1408c of detectors 1410c. The detectors are electrically connected to conductors 1412c, which can be gold, silver, copper, or any other suitable conductive material.

The detector submount 1400c is shown positioned under the protrusion 605b in a detector subassembly 1450 illustrated in FIG. 14D. A top-down view of the detector subassembly 1450 is also shown in FIG. 14E. In the detector subassembly 1450, a cylindrical housing 1430 is disposed on the submount 1400c. The cylindrical housing 1430 includes a transparent cover 1432, upon which the protrusion 605b is disposed. Thus, as shown in FIG. 14D, a gap 1434 exists between the detectors 1410c and the protrusion 605b. The height of this gap 1434 can be chosen to increase or maximize the amount of light that impinges on the detectors 1410c.

The cylindrical housing 1430 can be made of metal, plastic, or another suitable material. The transparent cover 1432 can be fabricated from glass or plastic, among other materials. The cylindrical housing 1430 can be attached to the submount 1400c at the same time or substantially the same time as the detectors 1410c to reduce manufacturing costs. A shape other than a cylinder can be selected for the housing 1430 in various embodiments.

In certain embodiments, the cylindrical housing 1430 (and transparent cover 1432) forms an airtight or substantially airtight or hermetic seal with the submount 1400c. As a result, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c from fluids and vapors that can cause corrosion. Advantageously, in certain embodiments, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c more effectively than cur-

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rently-available resin epoxies, which are sometimes applied to solder joints between conductors and detectors.

In embodiments where the cylindrical housing 1430 is at least partially made of metal, the cylindrical housing 1430 can provide noise shielding for the detectors 1410c. For 5 example, the cylindrical housing 1430 can be soldered to a ground connection or ground plane on the submount 1400c. which allows the cylindrical housing 1430 to reduce noise. In another embodiment, the transparent cover 1432 can include a conductive material or conductive layer, such as conductive glass or plastic. The transparent cover 1432 can include any of the features of the noise shields 790 described

The protrusion 605b includes the chamfered edges  $607_{15}$ described above with respect to FIG. 6E. These chamfered edges 607 can allow a patient to more comfortably slide a finger over the protrusion 605b when inserting the finger into the sensor 301f.

which includes the detectors 1410c on the substrate 1400c. The substrate 1400c is enclosed by a shielding enclosure 1490, which can include the features of the shielding enclosures 790a, 790b described above (see also FIG. 17). The shielding enclosure 1490 can be made of metal. The shield-25 ing enclosure 1490 includes a window 1492a above the detectors 1410c, which allows light to be transmitted onto the detectors 1410c.

A noise shield 1403 is disposed above the shielding enclosure 1490. The noise shield 1403, in the depicted 30 embodiment, includes a window 1492a corresponding to the window 1492a. Each of the windows 1492a, 1492b can include glass, plastic, or can be an opening without glass or plastic. In some embodiments, the windows 1492a, 1492b may be selected to have different sizes or shapes from each 35

The noise shield 1403 can include any of the features of the conductive glass described above. In the depicted embodiment, the noise shield 1403 extends about threequarters of the length of the detector shell 306f. In other 40 embodiments, the noise shield 1403 could be smaller or larger. The noise shield 1403 could, for instance, merely cover the detectors 1410c, the submount 1400c, or a portion thereof. The noise shield 1403 also includes a stop 1413 for positioning a measurement site within the sensor 301f. 45 Advantageously, in certain embodiments, the noise shield 1403 can reduce noise caused by light piping.

A thermistor 1470 is also shown. The thermistor 1470 is attached to the submount 1400c and protrudes above the noise shield 1403. As described above, the thermistor 1470 50 can be employed to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby providing more accurate data useful in detecting blood analytes like 55 glucose.

In the depicted embodiment, the detectors 1410c are not enclosed in the cylindrical housing 1430. In an alternative embodiment, the cylindrical housing 1430 encloses the detectors 1410c and is disposed under the noise shield 1403. 60 In another embodiment, the cylindrical housing 1430 encloses the detectors 1410c and the noise shield 1403 is not used. If both the cylindrical housing 1403 and the noise shield 1403 are used, either or both can have noise shielding

FIG. 14G illustrates the detector shell 306f of FIG. 14F, with the finger bed 310f disposed thereon. FIG. 14H illus38

trates the detector shell 306f of FIG. 14G, with the protrusion 605b disposed in the finger bed 310f.

FIG. 14I illustrates a cutaway view of the sensor 301f. Not all features of the sensor 301f are shown, such as the protrusion 605b. Features shown include the emitter and detector shells 304f, 306f, the flaps 307f, the heat sink 350f and fins 351f, the finger bed 310f, and the noise shield 1403.

In addition to these features, emitters 1404 are depicted in the emitter shell 304f. The emitters 1404 are disposed on a submount 1401, which is connected to a circuit board 1419. The emitters 1404 are also enclosed within a cylindrical housing 1480. The cylindrical housing 1480 can include all of the features of the cylindrical housing 1430 described above. For example, the cylindrical housing 1480 can be made of metal, can be connected to a ground plane of the submount 1401 to provide noise shielding, and can include a transparent cover 1482.

The cylindrical housing 1480 can also protect the emitters FIG. 14F illustrates a portion of the detector shell 306f, 20 1404 from fluids and vapors that can cause corrosion. Moreover, the cylindrical housing 1480 can provide a gap between the emitters 1404 and the measurement site (not shown), which can allow light from the emitters 1404 to even out or average out before reaching the measurement

> The heat sink 350f, in addition to including the fins 351f, includes a protuberance 352f that extends down from the fins 351f and contacts the submount 1401. The protuberance 352f can be connected to the submount 1401, for example, with thermal paste or the like. The protuberance 352f can sink heat from the emitters 1404 and dissipate the heat via the fins **351***f*.

> FIGS. 15A and 15B illustrate embodiments of sensor portions 1500A, 15008 that include alternative heat sink features to those described above. These features can be incorporated into any of the sensors described above. For example, any of the sensors above can be modified to use the heat sink features described below instead of or in addition to the heat sink features of the sensors described above.

> The sensor portions 1500A, 1500B shown include LED emitters 1504; however, for ease of illustration, the detectors have been omitted. The sensor portions 1500A, 1500B shown can be included, for example, in any of the emitter shells described above.

> The LEDs 1504 of the sensor portions 1500A, 1500B are connected to a substrate or submount 1502. The submount 1502 can be used in place of any of the submounts described above. The submount 1502 can be a non-electrically conducting material made of any of a variety of materials, such as ceramic, glass, or the like. A cable 1512 is attached to the submount 1502 and includes electrical wiring 1514, such as twisted wires and the like, for communicating with the LEDs 1504. The cable 1512 can correspond to the cables 212 described above.

> Although not shown, the cable 1512 can also include electrical connections to a detector. Only a portion of the cable 1512 is shown for clarity. The depicted embodiment of the cable 1512 includes an outer jacket 1510 and a conductive shield 1506 disposed within the outer jacket 1510. The conductive shield 1506 can be a ground shield or the like that is made of a metal such as braided copper or aluminum. The conductive shield **1506** or a portion of the conductive shield 1506 can be electrically connected to the submount 1502 and can reduce noise in the signal generated by the sensor 1500A, 1500B by reducing RF coupling with the wires 1514. In alternative embodiments, the cable 1512 does not have a conductive shield. For example, the cable 1512

could be a twisted pair cable or the like, with one wire of the twisted pair used as a heat sink.

Referring specifically to FIG. 15A, in certain embodiments, the conductive shield 1506 can act as a heat sink for the LEDs 1504 by absorbing thermal energy from the LEDs 5 1504 and/or the submount 1502. An optional heat insulator 1520 in communication with the submount 1502 can also assist with directing heat toward the conductive shield 1506. The heat insulator 1520 can be made of plastic or another suitable material. Advantageously, using the conductive 10 shield 1506 in the cable 1512 as a heat sink can, in certain embodiments, reduce cost for the sensor.

Referring to FIG. 15B, the conductive shield 1506 can be attached to both the submount 1502 and to a heat sink layer 1530 sandwiched between the submount 1502 and the 15 optional insulator 1520. Together, the heat sink layer 1530 and the conductive shield 1506 in the cable 1512 can absorb at least part of the thermal energy from the LEDs and/or the submount 1502.

FIGS. 15C and 15D illustrate implementations of a sensor 20 portion 1500C that includes the heat sink features of the sensor portion 1500A described above with respect to FIG. 15A. The sensor portion 1500C includes the features of the sensor portion 1500A, except that the optional insulator 1520 is not shown. FIG. 15D is a side cutaway view of the 25 sensor portion 1500C that shows the emitters 1504.

The cable 1512 includes the outer jacket 1510 and the conductive shield 1506. The conductive shield 1506 is soldered to the submount 1502, and the solder joint 1561 is shown. In some embodiments, a larger solder joint 1561 can 30 assist with removing heat more rapidly from the emitters 1504. Various connections 1563 between the submount 1502 and a circuit board 1519 are shown. In addition, a cylindrical housing 1580, corresponding to the cylindrical housing 1480 of FIG. 14I, is shown protruding through the circuit board 35 1519. The emitters 1504 are enclosed in the cylindrical housing 1580.

FIGS. 15E and 15F illustrate implementations of a sensor portion 1500E that includes the heat sink features of the sensor portion 1500B described above with respect to FIG. 40 15B. The sensor portion 1500E includes the heat sink layer 1530. The heat sink layer 1530 can be a metal plate, such as a copper plate or the like. The optional insulator 1520 is not shown. FIG. 15F is a side cutaway view of the sensor portion 1500E that shows the emitters 1504.

In the depicted embodiment, the conductive shield 1506 of the cable 1512 is soldered to the heat sink layer 1530 instead of the submount 1502. The solder joint 1565 is shown. In some embodiments, a larger solder joint 1565 can assist with removing heat more rapidly from the emitters 50 1504. Various connections 1563 between the submount 1502 and a circuit board 1519 are shown. In addition, the cylindrical housing 1580 is shown protruding through the circuit board 1519. The emitters 1504 are enclosed in the cylindrical housing 1580.

FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described above with respect to FIGS. 1 through 15F. Referring to FIG. 15G, the circuit board 1519 includes a female connector 1575 that mates with a male connector 1577 connected to a 60 daughter board 1587. The daughter board 1587 includes connections to the electrical wiring 1514 of the cable 1512. The connected boards 1519, 1587 are shown in FIG. 15H. Also shown is a hole 1573 that can receive the cylindrical housing 1580 described above.

Advantageously, in certain embodiments, using a daughter board 1587 to connect to the circuit board 1519 can

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enable connections to be made more easily to the circuit board **1519**. In addition, using separate boards can be easier to manufacture than a single circuit board **1519** with all connections soldered to the circuit board **1519**.

FIG. 15I illustrates an exemplary architecture for frontend interface 108 as a transimpedance-based front-end. As noted, front-end interfaces 108 provide an interface that adapts the output of detectors 106 into a form that can be handled by signal processor 110. As shown in this figure, sensor 101 and front-end interfaces 108 may be integrated together as a single component, such as an integrated circuit. Of course, one skilled in the art will recognize that sensor 101 and front end interfaces 108 may comprise multiple components or circuits that are coupled together.

Front-end interfaces 108 may be implemented using transimpedance amplifiers that are coupled to analog to digital converters in a sigma delta converter. In some embodiments, a programmable gain amplifier (PGA) can be used in combination with the transimpedance-based front-ends. For example, the output of a transimpedance-based front-end may be output to a sigma-delta ADC that comprises a PGA. A PGA may be useful in order to provide another level of amplification and control of the stream of signals from detectors 106. The PGA may be an integrated circuit or built from a set of micro-relays. Alternatively, the PGA and ADC components in converter 900 may be integrated with the transimpedance-based front-end in sensor 101.

Due to the low-noise requirements for measuring blood analytes like glucose and the challenge of using multiple photodiodes in detector 106, the applicants developed a noise model to assist in configuring front-end 108. Conventionally, those skilled in the art have focused on optimizing the impedance of the transimpedance amplifiers to minimize noise.

However, the following noise model was discovered by the applicants:

Noise=
$$\sqrt{aR+bR^2}$$
, where:

aR is characteristic of the impedance of the transimpedance amplifier; and

bR<sup>2</sup> is characteristic of the impedance of the photodiodes in detector and the number of photodiodes in detector 106.

The foregoing noise model was found to be helpful at least in part due to the high SNR required to measure analytes like glucose. However, the foregoing noise model was not previously recognized by artisans at least in part because, in conventional devices, the major contributor to noise was generally believed to originate from the emitter or the LEDs. Therefore, artisans have generally continued to focus on reducing noise at the emitter.

However, for analytes like glucose, the discovered noise model revealed that one of the major contributors to noise was generated by the photodiodes. In addition, the amount of noise varied based on the number of photodiodes coupled to a transimpedance amplifier. Accordingly, combinations of various photodiodes from different manufacturers, different impedance values with the transimpedance amplifiers, and different numbers of photodiodes were tested as possible embodiments.

In some embodiments, different combinations of transimpedance to photodiodes may be used. For example, detectors 1-4 (as shown, e.g., in FIG. 12A) may each comprise four photodiodes. In some embodiments, each detector of four photodiodes may be coupled to one or more transimpedance amplifiers. The configuration of these amplifiers may be set according to the model shown in FIG. 15J.

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Alternatively, each of the photodiodes may be coupled to its own respective transimpedance amplifier. For example, transimpedance amplifiers may be implemented as integrated circuits on the same circuit board as detectors 1-4. In this embodiment, the transimpedance amplifiers may be 5 grouped into an averaging (or summing) circuit, which are known to those skilled in the art, in order to provide an output stream from the detector. The use of a summing amplifier to combine outputs from several transimpedance amplifiers into a single, analog signal may be helpful in 10 improving the SNR relative to what is obtainable from a single transimpedance amplifier. The configuration of the transimpedance amplifiers in this setting may also be set according to the model shown in FIG. 15J.

As yet another alternative, as noted above with respect to 15 FIGS. 12E through 12H, the photodiodes in detectors 106 may comprise multiple active areas that are grouped together. In some embodiments, each of these active areas may be provided its own respective transimpedance. This form of pairing may allow a transimpedance amplifier to be 20 better matched to the characteristics of its corresponding photodiode or active area of a photodiode.

As noted, FIG. **15**J illustrates an exemplary noise model that may be useful in configuring transimpedance amplifiers. As shown, for a given number of photodiodes and a desired 25 SNR, an optimal impedance value for a transimpedance amplifier could be determined.

For example, an exemplary "4 PD per stream" sensor 1502 is shown where detector 106 comprises four photodiodes 1502. The photodiodes 1502 are coupled to a single 30 transimpedance amplifier 1504 to produce an output stream 1506. In this example, the transimpedance amplifier comprises 10 M $\Omega$  resistors 1508 and 1510. Thus, output stream 1506 is produced from the four photodiodes (PD) 1502. As shown in the graph of FIG. 15J, the model indicates that 35 resistance values of about 10 M $\Omega$  may provide an acceptable SNR for analytes like glucose.

However, as a comparison, an exemplary "1 PD per stream" sensor **1512** is also shown in FIG. **15J**. In particular, sensor **1512** may comprise a plurality of detectors **106** that 40 each comprises a single photodiode **1514**. In addition, as shown for this example configuration, each of photodiodes **1514** may be coupled to respective transimpedance amplifiers **1516**, e.g., 1 PD per stream. Transimpedance amplifiers are shown having 40 M $\Omega$  resistors **1518**. As also shown in 45 the graph of FIG. **15J**, the model illustrates that resistance values of 40 MO for resistors **1518** may serve as an alternative to the 4 photodiode per stream architecture of sensor **1502** described above and yet still provide an equivalent SNR.

Moreover, the discovered noise model also indicates that utilizing a 1 photodiode per stream architecture like that in sensor **1512** may provide enhanced performance because each of transimpedance amplifiers **1516** can be tuned or optimized to its respective photodiodes **1518**. In some 55 embodiments, an averaging component **1520** may also be used to help cancel or reduce noise across photodiodes **1518**.

For purposes of illustration, FIG. 15K shows different architectures (e.g., four PD per stream and one PD per stream) for various embodiments of a sensor and how 60 components of the sensor may be laid out on a circuit board or substrate. For example, sensor 1522 may comprise a "4 PD per stream" architecture on a submount 700 in which each detector 106 comprises four (4) photodiodes 1524. As shown for sensor 1522, the output of each set of four 65 photodiodes 1524 is then aggregated into a single transimpedance amplifier 1526 to produce a signal.

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As another example, a sensor **1528** may comprise a "1 PD per stream" architecture on submount **700** in which each detector **106** comprises four (4) photodiodes **1530**. In sensor **1528**, each individual photodiode **1530** is coupled to a respective transimpedance amplifier **1532**. The output of the amplifiers **1532** may then be aggregated into averaging circuit **1520** to produce a signal.

As noted previously, one skilled in the art will recognize that the photodiodes and detectors may be arranged in different fashions to optimize the detected light. For example, sensor 1534 illustrates an exemplary "4 PD per stream" sensor in which the detectors 106 comprise photodiodes 1536 arranged in a linear fashion. Likewise, sensor 1538 illustrates an exemplary "1 PD per stream" sensor in which the detectors comprise photodiodes 1540 arranged in a linear fashion.

Alternatively, sensor 1542 illustrates an exemplary "4 PD per stream" sensor in which the detectors 106 comprise photodiodes 1544 arranged in a two-dimensional pattern, such as a zig-zag pattern. Sensor 1546 illustrates an exemplary "1 PD per stream" sensor in which the detectors comprise photodiodes 1548 also arranged in a zig-zag pattern.

FIG. 15L illustrates an exemplary architecture for a switched-capacitor-based front-end. As shown, front-end interfaces 108 may be implemented using switched capacitor circuits and any number of front-end interfaces 108 may be implemented. The output of these switched capacitor circuits may then be provided to a digital interface 1000 and signal processor 110. Switched capacitor circuits may be useful in system 100 for their resistor free design and analog averaging properties. In particular, the switched capacitor circuitry provides for analog averaging of the signal that allows for a lower smaller sampling rate (e.g., 2 KHz sampling for analog versus 48 KHz sampling for digital designs) than similar digital designs. In some embodiments, the switched capacitor architecture in front end interfaces 108 may provide a similar or equivalent SNR to other front end designs, such as a sigma delta architecture. In addition, a switched capacitor design in front end interfaces 108 may require less computational power by signal processor 110 to perform the same amount of decimation to obtain the same

FIGS. 16A and 16B illustrate embodiments of disposable optical sensors 1600. In an embodiment, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be incorporated into the disposable sensors 1600 shown. For instance, the sensors 1600 can be used as the sensors 101 in the system 100 described above with respect to FIG. 1. Moreover, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be implemented in other disposable sensor designs that are not depicted herein.

The sensors 1600 include an adult/pediatric sensor 1610 for finger placement and a disposable infant/neonate sensor 1602 configured for toe, foot or hand placement. Each sensor 1600 has a tape end 1610 and an opposite connector end 1620 electrically and mechanically interconnected via a flexible coupling 1630. The tape end 1610 attaches an emitter and detector to a tissue site. Although not shown, the tape end 1610 can also include any of the protrusion, shielding, and/or heat sink features described above. The emitter illuminates the tissue site and the detector generates a sensor signal responsive to the light after tissue absorption, such as absorption by pulsatile arterial blood flow within the tissue site.

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The sensor signal is communicated via the flexible coupling 1630 to the connector end 1620. The connector end 1620 can mate with a cable (not shown) that communicates the sensor signal to a monitor (not shown), such as any of the cables or monitors shown above with respect to FIGS. 2A 5 through 2D. Alternatively, the connector end 1620 can mate directly with the monitor.

FIG. 17 illustrates an exploded view of certain of the components of the sensor 301f described above. A heat sink 1751 and a cable 1781 attach to an emitter shell 1704. The 10 emitter shell attaches to a flap housing 1707. The flap housing 1707 includes a receptacle 1709 to receive a cylindrical housing 1480/1580 (not shown) attached to an emitter submount 1702, which is attached to a circuit board 1719.

A spring 1787 attaches to a detector shell 1706 via pins 15 1783, 1785, which hold the emitter and detector shells 1704, 1706 together. A support structure 1791 attaches to the detector shell 1706, which provides support for a shielding enclosure 1790. A noise shield 1713 attaches to the shielding enclosure 1790. A detector submount 1700 is disposed 20 inside the shielding enclosure 1790. A finger bed 1710 provides a surface for placement of the patient's finger. Finger bed 1710 may comprise a gripping surface or gripping features, which may assist in placing and stabilizing a patient's finger in the sensor. A partially cylindrical protru- 25 sion 1705 may also be disposed in the finger bed 1710. As shown, finger bed 1710 attaches to the noise shield 1703. The noise shield 1703 may be configured to reduce noise, such as from ambient light and electromagnetic noise. For example, the noise shield 1703 may be constructed from 30 materials having an opaque color, such as black or a dark blue, to prevent light piping.

Noise shield 1703 may also comprise a thermistor 1712. The thermistor 1712 may be helpful in measuring the temperature of a patient's finger. For example, the thermistor 35 1712 may be useful in detecting when the patient's finger is reaching an unsafe temperature that is too hot or too cold. In addition, the temperature of the patient's finger may be useful in indicating to the sensor the presence of low perfusion as the temperature drops. In addition, the thermistor 1712 may be useful in detecting a shift in the characteristics of the water spectrum in the patient's finger, which can be temperature dependent.

Moreover, a flex circuit cover 1706 attaches to the pins 1783, 1785. Although not shown, a flex circuit can also be 45 provided that connects the circuit board 1719 with the submount 1700 (or a circuit board to which the submount 1700 is connected). A flex circuit protector 1760 may be provided to provide a barrier or shield to the flex circuit (not shown). In particular, the flex circuit protector 1760 may 50 also prevent any electrostatic discharge to or from the flex circuit. The flex circuit protector 1760 may be constructed from well known materials, such as a plastic or rubber materials.

FIG. 18 shows the results obtained by an exemplary 55 sensor 101 of the present disclosure that was configured for measuring glucose. This sensor 101 was tested using a pure water ex-vivo sample. In particular, ten samples were prepared that ranged from 0-55 mg/dL. Two samples were used as a training set and eight samples were then used as a test population. As shown, embodiments of the sensor 101 were able to obtain at least a standard deviation of 13 mg/dL in the training set and 11 mg/dL in the test population.

FIG. 19 shows the results obtained by an exemplary sensor 101 of the present disclosure that was configured for 65 measuring glucose. This sensor 101 was tested using a turbid ex-vivo sample. In particular, 25 samples of water/glucose/

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Liposyn were prepared that ranged from 0-55 mg/dL. Five samples were used as a training set and 20 samples were then used as a test population. As shown, embodiments of sensor 101 were able to obtain at least a standard deviation of 37 mg/dL in the training set and 32 mg/dL in the test population.

FIGS. 20 through 22 shows other results that can be obtained by an embodiment of system 100. In FIG. 20, 150 blood samples from two diabetic adult volunteers were collected over a 10-day period. Invasive measurements were taken with a YSI glucometer to serve as a reference measurement. Noninvasive measurements were then taken with an embodiment of system 100 that comprised four LEDs and four independent detector streams. As shown, the system 100 obtained a correlation of about 85% and Arms of about 31 mg/dL.

In FIG. 21, 34 blood samples were taken from a diabetic adult volunteer collected over a 2-day period. Invasive measurements were also taken with a glucometer for comparison. Noninvasive measurements were then taken with an embodiment of system 100 that comprised four LEDs in emitter 104 and four independent detector streams from detectors 106. As shown, the system 100 was able to attain a correlation of about 90% and Arms of about 22 mg/dL.

The results shown in FIG. 22 relate to total hemoglobin testing with an exemplary sensor 101 of the present disclosure. In particular, 47 blood samples were collected from nine adult volunteers. Invasive measurements were then taken with a CO-oximeter for comparison. Noninvasive measurements were taken with an embodiment of system 100 that comprised four LEDs in emitter 104 and four independent detector channels from detectors 106. Measurements were averaged over 1 minute. As shown, the testing resulted in a correlation of about 93% and Arms of about 0.8 mg/dL.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

While certain embodiments of the inventions disclosed herein have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions disclosed herein. Indeed, the novel methods and systems described herein can be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein can be made without departing from the spirit of the inventions disclosed herein. The claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of certain of the inventions disclosed herein.

What is claimed is:

1. A user-worn physiological measurement device that defines a plurality of optical paths, the physiological measurement device comprising:

one or more emitters configured to emit light into tissue of a user;

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- a first set of photodiodes positioned on a first surface and surrounded by a wall that is operably connected to the first surface, wherein:
  - the first set of photodiodes comprises at least four photodiodes, and
  - the photodiodes of the first set of photodiodes are connected to one another in parallel to provide a first signal stream;
- a second set of photodiodes positioned on the first surface and surrounded by the wall, wherein:
  - the second set of photodiodes comprises at least four photodiodes, and
  - the photodiodes of the second set of photodiodes are connected to one another in parallel to provide a second signal stream; and
- a cover located above the wall and comprising a single protruding convex surface configured to be located between tissue of the user and the first and second sets of photodiodes when the physiological measurement device is worn by the user.
- wherein the physiological measurement device provides a plurality of optical paths, wherein each of the optical paths:
  - exits an emitter of the one or more emitters, passes through tissue of the user.
  - passes through the single protruding convex surface, and
  - arrives at a corresponding photodiode of the at least one of the first or second sets of photodiodes, the corresponding photodiode configured to receive light emitted by the emitter after traversal by the light of a corresponding optical path of the plurality of optical paths and after attenuation of the light by tissue of the
- 2. The user-worn physiological measurement device of 35 claim 1 further comprising:
  - preprocessing electronics configured to preprocess at least one of the first signal stream or the second signal
- 3. The user-worn physiological measurement device of 40 claim 2, wherein the preprocessing comprises adapting the at least one of the first signal stream or the second signal stream.
- **4**. The user-worn physiological measurement device of claim **3**, wherein the preprocessing further comprises amplifying the at least one of the first signal stream or the second signal stream.
- 5. The user-worn physiological measurement device of claim 4, wherein the preprocessing further comprises converting the at least one of the first signal stream or the second 50 signal stream from analog to digital.
- **6.** The user-worn physiological measurement device of claim **2**, wherein the preprocessing electronics comprise at least:
  - a first common amplifier configured to receive the first 55 signal stream from the first set of photodiodes at an input of the first common amplifier and at least amplify the first signal stream, and
  - a second common amplifier configured to receive the second signal stream from the second set of photo- 60 diodes at an input of the second common amplifier and at least amplify the second signal stream.
- 7. The user-worn physiological measurement device of claim 6, wherein at least the photodiodes of the first set of photodiodes are arranged such that a first photodiode and a 65 second photodiode are arranged across from each other on opposite sides of a central point along a first axis, and a third

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photodiode and a fourth photodiode are arranged across from each other on opposite sides of the central point along a second axis which is different from the first axis.

- **8**. The user-worn physiological measurement device of 5 claim **6** further comprising:
  - a plurality of windows, wherein each of the photodiodes of the first set of photodiodes and the second set of photodiodes has a corresponding window of the plurality of windows that allows light to pass through to the photodiode,
  - wherein each of the optical paths further:
    passes through a corresponding window of the plurality
    of windows.
- 9. The user-worn physiological measurement device of claim 8, wherein the single protruding convex surface protrudes a height between 1 millimeter and 3 millimeters.
  - 10. The user-worn physiological measurement device of claim 9 further comprising:
    - one or more processors configured to:
      - receive a signal stream responsive to at least one of the first signal stream or the second signal stream, wherein the signal stream is responsive to at least a physiological parameter of the user; and
        - process the signal stream to determine measurements of the physiological parameter;
    - a network interface configured to communicate with a handheld computing device;
    - a touch-screen display configured to provide a user interface, wherein:
      - the user interface is configured to display indicia responsive to the measurements of the physiological parameter, and
      - an orientation of the user interface is configurable responsive to a user input; and
    - a storage device configured to at least temporarily store at least the measurements of the physiological parameter.
  - 11. The user-worn physiological measurement device of claim 10, wherein the physiological parameter comprises at least one of: pulse rate, glucose, oxygen, oxygen saturation, methemoglobin, total hemoglobin, carboxyhemoglobin, or carbon monoxide.
  - 12. The user-worn physiological measurement device of claim 11, wherein the attenuated light is reflected by the tierne
  - 13. The user-worn physiological measurement device of claim 12 further comprising:
    - a strap configured to position the physiological measurement device on the user, wherein the physiological measurement device comprises a single unit wearable by the user, the single unit encompassing at least: the one or more emitters, the first and second sets of photodiodes, the wall, the cover, the plurality of windows, the one or more processors, the network interface, and the storage device.
  - 14. The user-worn physiological measurement device of claim 13, wherein the network interface is configured to communicate at least the measurements of the physiological parameter to the handheld computing device.
  - 15. The user-worn physiological measurement device of claim 14, wherein the single protruding convex surface protrudes a height greater than 2 millimeters and less than 3 millimeters.
  - **16**. A user-worn physiological measurement device that defines a plurality of optical paths, the physiological measurement device comprising:
    - one or more emitters configured to emit light into tissue of a user;

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- a first set of photodiodes positioned on a first surface and surrounded by a wall that is operably connected to the first surface, wherein:
  - the first set of photodiodes comprises at least four photodiodes, and
  - the photodiodes of the first set of photodiodes are connected to one another in parallel to provide a first signal stream;
- a second set of photodiodes positioned on the first surface and surrounded by the wall, wherein:
  - the second set of photodiodes comprises at least four photodiodes, and
  - the photodiodes of the second set of photodiodes are connected to one another in parallel to provide a second signal stream;
- a cover located above the wall and comprising a single protruding convex surface configured to be located between tissue of the user and the first and second sets of photodiodes when the physiological measurement device is worn by the user;
- a plurality of windows, wherein each of the photodiodes of the first set of photodiodes and the second set of photodiodes has a corresponding window of the plurality of windows that allows light to pass through to the photodiode;
- preprocessing electronics configured to preprocess at least one of the first signal stream or the second signal stream, wherein the preprocessing electronics comprise at least:
  - a first common amplifier configured to receive the first signal stream from the first set of photodiodes at an input of the first common amplifier and at least amplify the first signal stream, and
  - a second common amplifier configured to receive the second signal stream from the second set of photodiodes at an input of the second common amplifier and at least amplify the second signal stream;

one or more processors configured to:

receive a signal stream responsive to at least one of the first signal stream or the second signal stream after 40 preprocessing of the at least one of the first signal stream and the second signal stream, wherein the signal stream is responsive to at least a physiological parameter of the user, and wherein the physiological parameter comprises at least one of: pulse rate,

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glucose, oxygen, oxygen saturation, methemoglobin, total hemoglobin, carboxyhemoglobin, or carbon monoxide; and

- process the signal stream to determine measurements of the physiological parameter;
- a network interface configured to communicate at least the measurements of the physiological parameter to a handheld computing device:
- a touch-screen display configured to provide a user interface, wherein the user interface is configured to display indicia responsive to the measurements of the physiological parameter;
- a storage device configured to at least temporarily store at least the measurements of the physiological parameter; and
- a strap configured to position the physiological measurement device on the user, wherein the physiological measurement device comprises a single unit wearable by the user, the single unit encompassing at least: the one or more emitters, the first and second sets of photodiodes, the wall, the cover, the plurality of windows, the one or more processors, the network interface, and the storage device,
- wherein the physiological measurement device provides a plurality of optical paths, wherein each of the optical paths:

exits an emitter of the one or more emitters,

passes through tissue of the user,

- passes through the single protruding convex surface and the corresponding window of the plurality of windows, and
- arrives at a corresponding photodiode of the at least one of the first or second sets of photodiodes, the corresponding photodiode configured to receive light emitted by the emitter after traversal by the light of a corresponding optical path of the plurality of optical paths and after attenuation of the light by tissue of the user, and

wherein the attenuated light is reflected by the tissue.

- 17. A physiological measurement system comprising:
- a user-worn physiological measurement device according to claim 16; and
- a handheld computing device in communication with the user-worn physiological measurement device.

\* \* \* \* \*